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A TRIAL OF THE IMPACT OF INTERVENTION IN THE GLOBAL MODEL

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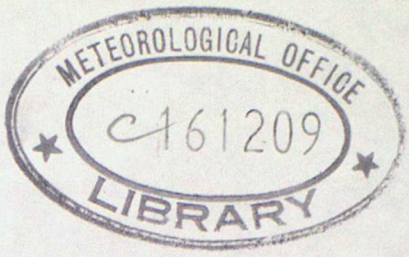

CENTRAL FORECASTING TECHNICAL NOTE NO.12

A TRIAL OF THE IMPACT OF INTERVENTION IN THE GLOBAL MODEL

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1.Introduction

Observational data received at Bracknell are continually monitored by the Intervention Bench in the Central Forecasting Office (CFO) prior to use in the operational Numerical Weather Prediction models. The Intervention Forecaster (IF) has the facilities to reject, correct or support (effectively increase the weight of) observations or elements of observations as well as create "bogus" observations of mean sea-level pressure (MSLP), wind, temperature, relative humidity or 500-1000hPa thickness to support existing observations or for use in data sparse areas. Collectively this manual action is known as Intervention.

In the past the impact of Intervention has been assessed by examining individual cases where it is suspected Intervention has had an impact. One such study was carried out by Woodage (1985). These cases have proved useful in assessing the short term impact in a limited geographical area. In 1990, the impact of bogus data in the old Fine-Mesh model was assessed in a wider study by examining cases randomly selected from a larger sample of cases where a significant amount of bogus data had been created (Heming, 1990(a)). However, in the autumn of 1992 the resources became available to undertake a far more comprehensive study by running the global model without any Intervention alongside the operational model for two weeks using the Parallel Suite (PS). This would provide results on a global scale which show the impact of Intervention not just on a single model run, but over a period of time and by the end of the period would be accurately simulating how the model would perform without any form of Intervention.

The PS was available between 10th and 27th October 1992 for the purpose of this experiment and during that period was run with all Intervention switched off. The PS uses exactly the same observations as operationally (except for bogus data in this case), but runs on a totally independent cycle. i.e. the background field for each run is generated by the previous PS model run. One 120 hour forecast was run per day by the PS from the 00GMT run of the model.

2.Method of Assessment

In previous impact studies verification of results has nearly always been by subjective means with some objective figures for Limited Area Model rainfall fields where appropriate. However, the PS incorporates a version of the objective verification scheme used operationally, so this was utilised to produce verification against analysis and verification against observations for all major meteorological fields and geographical areas during the study period. The PS

also incorporates an Observation Processing Database (OPD) which can be compared with the operational OPD to produce an objective assessment of the T+6 forecasts. A scheme to objectively assess forecast errors for tropical cyclones (TCs) is also run regularly for the operational model and could be used on the parallel run to produce a comparison of TC forecast performance with and without Intervention. During the trial all major fields were archived along with the verification information and difference charts were produced to allow a subjective assessment of interesting cases to be made in addition to the objective verification on completion of the experiment.

3.VERIFICATION OF THE RESULTS

3.1. Verification Against Analysis

Verification against analysis was carried out in real time as the experiment proceeded and the results archived for later examination. It is desirable to verify against the best available analysis in experiments such as this, which is usually taken to be the operational analysis. However, to do this in this experiment would require the assumption that Intervention has a positive impact in the analysis, which is what the experiment is setting out to determine in part. In any case, the PS verification scheme is set up to verify against its own rather than the operational analysis and the operational verification scheme verifies against its own operational analysis. Hence, the figures tabulated here are for the verification of forecasts for the Operational (OP) and No Intervention (NI) runs against their own analyses.

The verification system available to evaluate the results is only able to function by verifying all forecasts valid on a selected day. It is not possible to selectively verify depending on the data time of the forecast. Hence, if all forecasts from the NI run were to be verified the equivalent OP run statistics would contain figures from runs with data times outside the time window of the experiment. The only way to ensure the same sample of forecasts was verified for each run was to restrict the verification to all forecasts which were valid between 15th and 26th October. Unfortunately, this excludes some data from the results at either end of the experimental period, but this cannot be avoided.

Tables 1 and 2 show RMS and mean error statistics for each forecast time and field averaged over the period 15th October to 26th October for the whole globe for the OP and NI runs respectively. The run with the smaller error is indicated by a "✓".

The results show that the NI run was better overall for 250hPa winds. Results for 500hPa heights and temperatures were more mixed, with the OP run generally being better earlier in the forecast and the NI run better at later forecast times. The mean errors for surface wind, 850hPa wind and relative humidity were smaller for the OP run, but RMS errors were larger. MSLP and

250hPa temperature results indicate that the OP run was better at nearly all forecast times. The statistics broken down by geographical area (not shown) show that RMS errors for surface wind, 850hPa wind and relative humidity were smaller for the OP run in the southern hemisphere in contrast to the global errors. The smaller global RMS MSLP error for the OP run was totally due to southern hemisphere figures since the tropics and northern hemisphere indicated larger errors than the NI run. The differences between the errors for the two runs are generally small compared to the errors themselves, but show a clear division between larger errors in the OP run for winds, but smaller errors than the NI run for other categories.

3.2. Verification Against Observations

Verification against observations was also carried out in real time and the results archived for later examination. The observations used for verification included all corrections applied within the model (i.e. permanent and CFO corrections) and undergo a crude quality check against the analysis before being used. Surface observations used for verification are land synops, ships and drifters. Upper fields are verified against land and sea radiosonde reports only (i.e. not aireps, satobs or satellite sounding data).

Verification against observations is a better way to assess model performance than verification against analysis since it is using real data as the verification standard rather than model fields. However, its disadvantage is that observations are not evenly distributed across the globe and hence some large areas of model fields are not verified by this method. This is particularly important in this case since much of bogus data is created in data sparse areas and hence verification of the model in the vicinity of these data is not possible due to the lack of real observations. The statistics are for all forecasts verifying in the period 15th to 26th October for the reasons given in the previous section.

Tables 3 and 4 show RMS and mean error statistics for each forecast time and field averaged over the period 15th to 26th October for the whole globe for the OP and NI runs respectively. The run with the smaller error is indicated by a "✓".

These results are far more mixed than for the verification against analysis statistics. For MSLP the OP run has smaller RMS errors than the NI run, but slightly larger mean errors. The 500hPa height errors are definitely biased in favour of the NI run with similar results for 250hPa height. 500hPa temperature errors are very similar for both runs with neither performing better than the other overall. The difference between the runs for 250hPa temperatures are slightly larger and indicate that the OP run is better at early forecast times, but the NI run better later in the forecast. For 850hPa wind speeds and directions the NI run is the better overall. The 250hPa mean wind speed and direction errors favour the OP run, but the RMS errors are more

mixed. Surface wind results were mixed, but seem just to favour the OP run. Again, errors for 850hPa relative humidity were mixed, but overall seem to favour the NI run in this case.

Geographically, there were some variations in the performance of the OP and NI runs when verified against observations. Figures were obtained for four areas:- North Atlantic and North-West Europe, Northern Hemisphere north of 30°N, Southern Hemisphere south of 30°S and Tropics (30°N to 30°S). The breakdown for MSLP showed that the OP run gave better results south of 30°N than to the north. This agrees with the regional breakdown for verification against analysis. 250hPa and 500hPa height fields were similar across the four regions except that south of 30°N the OP and NI 500hPa height fields showed similar error characteristics compared to the errors north of 30°N which were considerably smaller for the NI run. There were no regional variations in the 500hPa and 250hPa temperature fields. The only notable regional variation for 850hPa wind was that mean wind speeds and directions were all better for the OP run north of 30°N, but showed more variation in the south. Surface winds and 850hPa relative humidity indicated that the OP run was slightly better in the tropics than in other regions.

It is interesting to note that of the 24 error categories listed in the global statistics in Tables 3 and 4 (mean and RMS for 12 different fields), in the analysis the OP run was better in 17 of them compared to 5 for the NI run. However, for all other forecast times except T+24 the NI run was better in more categories than the OP run - most noticeably at T+120 17 categories were better for the NI run compared to the OP run's 6. This would point to a conclusion that Intervention has a positive impact in the analysis, but when the effects are fed through to the forecast the impact is often nullified and even reversed. This agrees with results obtained from Intervention experiments carried out by Woodage (1985).

Figure 8 is a graphical representation of the RMS errors for MSLP tabulated in Tables 3 and 4. It is typical of all the error statistics for both verification against observations and analysis in so far as it shows that the relative difference between the OP and NI errors is very small compared to the absolute errors. Hence, it must be borne in mind that the above assessment of which run is the better is based on marginal differences between the two sets of error statistics.

3.3. Verification of T+6 Forecasts Against Observations using the OPD

The OPD records chosen for comparison were as follows:-
- ship surface pressures
- ship winds
- AIREP winds
- TEMPSHIP temperatures

- TEMPSHIP humidities

Data for the period 10th to 27th October at times 00, 06, 12 and 18GMT were used i.e. a total of 72 separate OPD datum times. Observation minus Background (O-B) statistics are mainly considered here along with some flagging results.

The variables studied in this section cover pressure, temperature, winds and humidity , primarily over the ocean. It is over the ocean where differences are most likely to occur since most Intervention is applied there and we are only considering six hour forecasts. AIREP winds are studied rather than TEMPSHIPs because of their greater quantity and because Intervention on winds is often undertaken in and around high level jets where the AIREPs are principally located.

Note that fixed buoys and rigs are included with ships. ASDARs are not included with AIREPs.

CFO corrected observations are excluded from the comparison since they do not appear in the PS OPD and we wished to start with the same number of observations in the two sets of OPD records.

It was found that the number of AIREP records with the Element Presence Indicator (EPI) set for winds, also the number of ship records with the EPI set for winds and pressures, was slightly different between the NI and OP runs. The NI run had slightly more (less than 10 more) records with the EPI set for these observation types and variables than the OP run. This is presumably as the result of some Intervention action, but the details have not been investigated since the impact on these results is minimal.

The fact that the NI and OP background fields are different has led to other causes of differences in sample sizes, when for example criteria based on observation/background differences are used to exclude observation outliers and when results are classified according to mean observation and background speed. Again these factors do not affect the overall conclusions.

a) Ship pressure results

Results were classified according to latitude band. Observations were excluded where the O-B difference exceeded 5hPa. This condition excluded 1231 ships in the NI run and 1228 ships in the OP run.

The results are shown in Table 5 - a "✓" indicates the mean O-B difference was smaller in absolute terms or RMS difference is smaller. Clearly there is little difference between the O-B results for the NI and OP runs.

b) Ship wind results

Two comparisons were made for ship winds; one using all ships and one using a subset - of "good" ships - obtained by extracting records from ship identifiers giving a small RMS O-B difference for October taking into account the O-B differences for neighbouring ships. In both cases results were classified according to mean wind speed of the observation and background by its latitude band.

i)All ships. Results for the whole globe are shown in Table 6. Observations were excluded where the O-B was more than 25 m/s. The numbers excluded were 126 for NI run and 151 for OP run. The greater number of reports flagged for the OP run is probably because the mean background speed is greater, giving higher likelihood of the rejection criterion being exceeded.

The mean and RMS O-B differences are seen to be lower for the OP run although differences are quite small compared to the large mean bias which exists between the ship and model winds - particularly at higher speeds. Further details of surface wind biases are examined by Leighton (1993).

ii)"Good" ships. Results for different latitude bands and all wind speeds combined are shown in Table 7. The final column shows the number flagged at buddy check stage. Observations were excluded where the observation speed was more than 40 m/s. The number excluded was 19 in both runs.

Again the mean and RMS differences tend to be slightly smaller for the OP run. The number of flagged observations is also smaller for the OP run (which since this is for a generally "good" set of ships is presumably a desirable result). Note that the RMS vector wind difference may tend to be inflated somewhat for the OP run because the mean background speed (which has a lower limit but no upper limit) is higher than for the NI run. The same applies to the results for AIREP winds below.

c) AIREP wind results

Results were classified according to ocean area and mean of observation and background speed. The areas were :-

Area number

1	20-40°N 20-60°W	(southern part of North Atlantic)
2	40-60°N 20-60°W	(northern part of North Atlantic)
3	20-40°N 150°E-130°W	(southern part of North Pacific)
4	40-60°N 150°E-130°W	(northern part of North Pacific)
5	20-40°S 160°E-80°W	(northern part of South Pacific)

Observations were excluded where O-B vector differences were greater than 40 m/s. Number excluded : 201 for NI run and 112 for OP run. Tables 8-11 show statistics for various combinations of these areas.

Results for the AIREPs show a reduction in the O-B bias for the OP run compared with the NI run and fewer observations flagged. For the RMS difference, the global values in Table 11 (where all observations were included) indicate lower values for the OP run although the results for the ocean areas in Table 9 did not give a clear signal.

d) TEMPSHIP temperature results

Results are classified by latitude band and level. Observations were rejected where the O-B value was greater than 10 degrees Celsius. Number of levels rejected : 35 for the NI run and 36 for the OP run. The results can be found in Table 12 and indicate that there is little to choose between the NI and OP runs.

e) TEMPSHIP humidities

Results are again classified by latitude band and level. All observations were included. The results can be found in Table 13 and again indicate little to choose between the NI and OP runs.

Overall, these results suggest that for short period forecasts Intervention has had little impact on pressures, temperatures and humidities as measured by values at observation points. For both surface and high level winds, the OP run gives background speeds which are closer (i.e. stronger) to the observations than the NI run. The RMS O-B vector differences are also slightly reduced for the OP run. Associated with these results is the fact that there are fewer wind observations flagged by the quality control scheme in the OP run.

3.4. Objective Verification of Tropical Cyclone Forecast Positions

In the case of TCs Intervention will nearly always be in the form of bogus data inserted around the vortex to reposition and/or strengthen the model's circulation. Details of the facilities available to the IF for Intervention of TCs can be found in Hall et al. (1992).

The performance of the operational model in forecasting the positions of TCs is routinely monitored by a semi-automatic scheme which verifies the forecast position of the TC centre (identified by the point of maximum 850hPa vorticity) against the position given by the advisory messages received on the Global Telecommunications System. Details of the verification scheme can be found in documentation held by the author.

This scheme was used to verify the forecasts of TCs during the experiment period both for the OP and NI runs. During the period of the trial there were 10 active TCs, which gave a large enough sample of forecasts to make the verification statistically valid. Since the PS only ran a forecast once a day (at 00GMT) only forecasts from this hour have been included in the statistics. However, 12GMT analyses have been included since these were obtainable from the NI run. Tables 14 and 15 show the mean forecast error statistics for all storms over the trial period. Figure 9 shows the direct positional error results in graphical form.

It is immediately apparent from these statistics that Intervention has had a significant positive impact on the positional forecast of TCs. The mean analysis Direct Positional Error (DPE) was reduced by 58% with errors at T+24 and 48 reduced by 29%. Beyond T+48 the differences in the errors are small (4% at most) and the T+120 statistics indicate the NI run to be better on average. However, the sample of forecasts used in these later forecast times is small and one poor forecast can have a significant impact on the mean forecast error.

The OP statistics were based on a larger sample of forecasts since with Intervention the model tended to hold on to TCs longer into the forecast whereas the NI run dissipated them sooner and hence there were less forecasts to verify. The statistics were also produced for only the OP forecasts which had a valid NI forecast for the same time and the results differed by up to 7% from those shown here. However, the overall picture of Intervention significantly improving forecasts up to T+48 was unaltered.

The DX, DY, Cross-Track and Along-Track error statistics show more variability than the DPE, but overall reflect the positive impact of Intervention on TC forecasts. The inclusion of Intervention does not seem to have impacted one particular error category significantly more than any of the others.

Five of the ten TCs and most of the valid forecasts for this period were in the North-West Pacific basin. Hence a detailed regional breakdown of impact is not possible. However, it is worth noting that for the one TC in the North Atlantic analysis errors were halved on average and for the one TC in the South-West Indian Ocean analysis errors were almost cut by two-thirds. Some cases of TC forecasts will be highlighted in the subjective assessment to follow.

3.5. Subjective Verification of Selected Cases

Difference charts of many fields were produced during the trial and were used to identify any runs where the OP and NI analyses or forecasts tended to diverge. In many cases the runs diverged significantly late into the forecast, but at that stage the forecast errors were far larger than the differences between the

two runs and hence verification was not possible. However, a number of cases were identified where one run or the other was considered to be a better forecast and these are detailed below. Verifying analyses from the OP run only are shown unless the OP and NI analyses differ significantly in which case both verifying analyses are shown.

Case 1. DT 00GMT 13.10.92

This first case indicates how the use of Intervention both produces a better forecast of TC location and maintains a stronger circulation for longer. The T+72 forecasts show TC Yvette to the north-east of the Philippines. The OP forecast (Figure 1(a)) was 5hPa deeper and further north than the centre in the NI forecast (Figure 1(b)). The verifying analyses for the two runs (Figures 1(c) and (d)) also have significantly different depths due to Intervention, but both indicate a more northerly position was better. By T+120, the difference in position between the two runs was over 5 degrees (Figures 1(e) and (f)). The OP run was better as the OP verifying analysis shows (Figure 1(g)).

Case 2. DT 00GMT 17.10.92

Figures 2(a) and (b) show the T+120 forecast of 250hPa wind isotachs and at first glance look similar in the region of the jet to the west of the UK. However, a closer inspection shows that the OP forecast pushed the stronger winds further east across Wales and England producing differences of up to 30 knots between the forecasts. The verifying analysis (Figure 2(c)) shows that the OP run was better as winds in the west of the UK were even higher than in this forecast by up to 20 knots.

Case 3. DT 00GMT 20.10.92

This case again shows the clear positive impact of intervention on TC analyses and forecasts. Figures 3(a) and (b) show the analyses of four TCs : Babie in the South Indian Ocean and from west to east in the North Pacific TCs Angela, Colleen and Brian. The depth and position of all these TCs is different in the two analyses. From the objective statistics, positional analysis errors for these four TCs were 39km, 148km, 55km and 86km for the OP run, but were 429km, 251km, 328km and 333km for the NI run. As a result of the improved analyses the OP forecasts were also much better. The T+24 forecasts (Figures 3(c) and (d)) show that the NI forecast had rapidly moved TC Babie to the north-west and almost dissipated it. The positions of TCs Angela and Colleen were also different and the NI run had dissipated TC Brian. The verifying analyses for the two runs (Figures 3(e) and (f)) although different clearly show the OP run was the better of the two particularly for TCs Babie and Brian.

Case 4. DT 00GMT 21.10.92

The T+24 forecast for this time shows a difference in the structure of the low pressure complex to the south of South America. The OP run has a more distinct single low centre to the west of 90°W when compared with the NI run

(Figures 4(a) and (b)). Similarly, the 500hPa height forecasts (Figures 4(c) and (d)) show a stronger upper vortex in the OP run. The verifying analyses (Figures 4(e)-(h)) do not convincingly show that one run was better than the other since they are different for the two runs and each verifying analysis favours its own forecast. This is indicative of the fact that in the Southern Hemisphere the impact of Intervention is apparently longer lasting, since there are few observations in many of the ocean areas to pull the OP and NI runs back to a similar analysis once Intervention has caused them to diverge. Despite the differences in the verifying analyses the OP forecast seems to be just the better since the OP verifying analysis confirms a single low centre west of 90°W and the NI verifying analysis hints at this, particularly in the upper air structure, more than the NI forecast which has an elongated centre.

Case 5. DT 00GMT 22.10.92

The T+120 forecast from this time shows differences in the surface pattern over Australia. The NI run develops a low centre over the central and northern parts of the country whereas the OP run builds a ridge from the south so reducing the cyclonic development (see Figures 5(a) and (b)). The verifying analysis (Figure 5(c)) shows that the NI run was the best forecast as it developed the depression over central Australia and kept pressure lower to the south-west. Tracing the surface fields back it appears that this difference in the two T+120 forecasts developed slowly during the forecast from analyses which appear almost identical. Examination of other fields shows a distinct difference in the T+120 250hPa wind fields as Figures 5(d) and (e) show. The NI forecast extends a jet northwards over south-west Australia and extends another jet rearwards across central and western Australia. This difference can be traced back through the forecast to the analyses (Figures 5(f) and (g)) which show a difference of 5 knots over western Australia and most notably a difference of 12 knots in the jet core over the ocean to the west of Australia. An examination of observations in the area showed that no Intervention was carried out in the vicinity of these jets at the analysis time so the differences must have either fed through from Intervention carried out in previous runs or be related to Intervention on a wider scale. Looking on a wider scale reveals that TC Babie was not far away from this jet to the north-west and the impact of Intervention on this circulation alone has already been demonstrated both in the TC objective verification statistics and Case 3. The 250hPa wind analyses (Figures 5(f) and (g)) show that Intervention on TC Babie (located at 15°S 80°E) did affect the flow near the jet in question and hence may have been the ultimate cause of the OP run producing a poorer forecast over Australia. This cannot be established without a more detailed investigation, but the theory of bogussing to strengthen a TC circulation resulting in the spurious strengthening of a higher latitude jet due to the increased vertical motion and outflow produced was proved to be true in a case in the North Pacific detailed in a Central Forecasting Case Study Note (Heming, 1990(b)). Hence, this would seem to be the best explanation available for the differences in the forecast over Australia in this case.

Case 6. DT 00GMT 25.10.92

The T+96 forecast from this time is an example of the OP and NI runs being different, but neither being better overall. The OP forecast (Figure 6(a)) had a low centre of 979hPa to the west of Denmark. The NI forecast (Figure 6(b)) had a low centre of 985hPa to the south of Denmark. The verifying analysis (Figure 6(c)) had a low centre of 986hPa near East Anglia. The NI forecast had a better central pressure, but the OP run was slightly better positionally. The upper air charts (not shown) tell a similar story at this forecast time. At T+120 the differences were slightly more marked. The OP forecast (Figure 6(d)) had a single low centre over the Baltic. The NI forecast (Figure 6(e)) had the same, but also retained a secondary low to the west of Denmark. In the upper air it can be seen that the OP forecast (Figure 6(f)) is trying to develop a trough over the UK separate from the main vortex over the Baltic whereas the NI forecast (Figure 6(g)) was attempting to extend a trough right across the North Sea. The verifying analyses (Figures 6(h) and (i)) suggest that the OP forecast was just better in this area, but this case is typical of many examined in that there were noticeable differences between the runs, but forecast errors on a similar or larger scale than the differences make it difficult to determine whether one run or the other was better.

Case 7. DT 00GMT 26.10.92

There were notable differences in two areas for this DT. Figures 7(a)-(d) show large analysis differences in the region of the depression south of Newfoundland. Extensive support of ship observations by use of bogus data was responsible for this. By T+24 the upper air patterns did not differ greatly, but Figures 7(e) and (f) show that the OP run maintained the lower central pressure of the depression. The verifying analyses (Figures 7(g) and (h)) are different, but both indicate the OP forecast was better by having a deeper centre. Beyond this forecast time both runs dissipate the low centre.

In the Southern Hemisphere there were significant differences from T+48 onwards. The T+48 forecasts (Figures 7(i) and (j)) show that the OP forecast had a stronger wave than the NI forecast near 50°S 100°W. Consequently, by T+72 (Figures 7(k) and (l)) the OP run had a depression more than 10hPa deeper over southern Chile. The verifying analysis (Figure 7(m)) shows the OP forecast was much better in this respect. These differences can be traced back to an apparently small difference in the analysis of the depression near 60°S 135°W (Figures 7(n) and (o)). The OP analysis of the system is slightly deeper and further north. Since the time of this analysis was some two weeks into the experiment, this difference could have been due to the cumulative effect of Intervention over this period. However, there was a ship reporting near this depression with a pressure 5hPa below background which was supported by five bogus observations in the OP run. Hence, this is a possible explanation for the difference. Also at this forecast time the NI run had stronger waves near 50°S 15°E and 55°S 30°W than the OP run. The verifying

analysis does not feature these waves. The main depression was also located near 60°S 20°W by the OP run and 60°S 40°W by the NI run. The depression in the verifying analysis was much deeper than both and was positioned between the two at 30°W. By T+96 the depression over Chile had moved to the east of Argentina - the OP run being 8hPa deeper and positioned further south (Figures 7(p) and (q)). The verifying analysis (Figure 7(r)) confirms this was a better forecast.

The 00GMT 27.10.92 forecast also showed differences between the two run's forecasts of central pressure of depressions in the southern hemisphere of up to 6hPa. The verification varied between the OP and NI runs being the better of the two with, in most cases, the forecast errors being larger than the differences between the two runs.

4.Conclusions

The impact of Intervention has been assessed over a 17 day period in October 1992 by omitting all forms of it from a parallel run of the UK Met. Office global model. A full assimilation cycle and one 5-day forecast per day were run during the experiment period. Several verification techniques were employed which together can be used to build up an overall picture of the impact of Intervention in the model.

The verification against analysis statistics indicate that Intervention has a positive or neutral impact on all fields apart from winds at all levels which show a clear negative impact from the RMS figures. Regionally, Intervention has had a greater impact in the more data sparse southern hemisphere. When considering these results it must be noted that each run was verified against its own analysis which may result in an unfair comparison. If Intervention had a positive impact in the OP analysis and a lesser or greater, but still positive impact in the OP forecast (as was found in some cases by other verification methods) then it is possible that the error statistic for the OP forecast could be greater than that of the NI run which had a poorer analysis and forecast relative to the OP run, but the analysis and forecast were closer relative to each other than the OP analysis and forecast. These results may simply indicate, therefore, that the impact of Intervention on winds varies significantly between the analysis and forecast compared to other fields. The only way to substantiate this would be to verify each forecast against both the OP and NI analyses. However, this is not possible since verification against analysis was carried out in real time and archived for later examination and cannot be rerun retrospectively. Hence, these results must be viewed in the light of the results produced by other verification methods.

Verification against observations is a more reliable statistic since the same observations are used to verify both the OP and NI forecasts. Its main disadvantage is the sparsity of observations in some places which reduces the

area over which verification can take place. The results were more varied than the verification against analysis. The NI run gave better results for 500hPa and 250hPa heights, whereas the OP run was better overall for MSLP, 250hPa wind and surface winds. Results were mixed for 500hPa and 250hPa temperatures and 850hPa winds and humidities. It is interesting to note that the best results were obtained from the fields which are most commonly directly intervened on and the worst results from the fields which cannot be intervened on directly. Regionally, there were variations in the statistics. Better results for MSLP and 500hPa and 250hPa heights south of 30°N again show the greater impact of Intervention in more data sparse areas. However, OP 850hPa wind errors seem to be smaller in the area north of 30°N. Surface winds and 850hPa humidities were better for the OP run in the Tropics which indicates again the positive impact Intervention has on maintaining the circulation of TCs.

Verification of 6-hour forecasts against observations was carried out using OPD statistics and found that the main positive impact of Intervention was on the model's surface and 250hPa wind forecasts. There was a reduction in the tendency of the model to underpredict wind strengths as well as a reduction in the RMS errors. Other T+6 forecast fields were not significantly impacted by Intervention according to the statistics.

Verification of forecasts of TC movement shows the clearest positive impact of Intervention in all the categories examined. Significant reductions in positional errors were made in the analyses and forecasts up to T+48 by the inclusion of Intervention and the OP forecasts also tended to hold onto TC circulations longer into the forecast - not dissipating them as the NI forecasts frequently did.

The subjective assessment also highlighted the positive impact of Intervention on TC forecasts. The other cases examined showed firstly that Intervention has an impact on most forecasts, particularly later in the trial period after it had been omitted for some days, but the forecast errors were of a similar magnitude or were larger than the differences between the two runs making it difficult to judge which one was the better. Of those cases where a judgement could be made, the OP run was better more often than the NI run. Cases 4, 6 and 7 show a mixed impact which just favours the OP run. Cases 1, 2 and 3 show a clear positive impact of Intervention and Case 5 shows a negative impact of Intervention. This last case is interesting since the impact appears to be due to Intervention performed near a TC with the intention of having an impact on the TC circulation only. The forecasts for the TC were considerably improved, but the Intervention appears to have produced a detrimental impact on a wider scale.

On balance, from these results it can be concluded that Intervention has had a small positive impact overall, but the objective statistics and individual cases show some marked variations in impact when examined in more detail.

The results show that the best impact is on fields and features which can be directly intervened on (e.g. MSLP, TCs), whereas a negative impact can be made on fields and features not intervened on directly, but indirectly influenced by Intervention on other fields or nearby features (e.g. 500hPa height field, forecasts in Case 5). One-off case studies have not provided such detailed information in the past and hence this investigation has provided a broader picture of how Intervention can have an impact on analyses and forecast from the UK Met. Office global model.

A further trial of the impact of Intervention in both the global and limited area models is planned for the summer of 1993.

5.Acknowledgements

Section 3.3, verification using OPD statistics, was compiled and written by S.G.Smith formerly of CF5.

The experiment was carried out using the Central Forecasting Division Parallel Suite under the direction of C.B.Hynes of CF4.

6.References

Hall, C.D., Hunt, J.C.R., Radford, A.M., Carruthers, D.J. & Weng, W.S. 1992. Forecasting Tropical Cyclones and Near Surface Wind Conditions. ICSU/WMO International Symposium on Tropical Cyclone Disasters, Beijing October 1992.

Heming, J.T. 1990(a). Trial of the Impact of Bogus Data in the Fine-Mesh Model. Central Forecasting Technical Note No.4.

Heming, J.T. 1990(b). The Overstrengthening of a Jet Forecast Over the USA. Central Forecasting Case Study No.28.

Leighton, J.R. 1993. A Study of Wind Speed for the Six Classes of Marine Surface Observation. Central Forecasting Monitoring Note No.15.

Woodage, M.J. 1985. A Report on Intervention Experiments carried out with the 15-level Model. Met O 2b Technical Note No.103.

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		T+24	T+48	T+72	T+96	T+120
MSLP (hPa)	mean	0.00✓	0.00✓	-0.01✓	-0.01=	-0.01✓
	RMS	2.01✓	3.17✓	4.30✓	5.28✓	6.13
500hPa height (dam)	mean	-0.41✓	-0.66✓	-0.79✓	-0.86=	-0.91=
	RMS	1.64=	2.89✓	4.11✓	5.16	6.21
500hPa temperature (°C)	mean	-0.24✓	-0.39✓	-0.49=	-0.57=	-0.65=
	RMS	0.94=	1.52=	1.99	2.39	2.85
250hPa temperature (°C)	mean	-0.45✓	-0.83✓	-1.13✓	-1.35✓	-1.53✓
	RMS	1.17✓	1.81✓	2.30✓	2.69✓	3.04✓
850hPa vector wind (knots)	mean	0.19✓	0.48✓	0.86✓	1.13✓	1.22✓
	RMS	6.23	9.32	11.79	13.82	15.37
250hPa vector wind (knots)	mean	0.05	0.15	0.33=	0.39✓	0.39✓
	RMS	9.85	15.76	20.44	24.59	28.96
Surface vector wind (knots)	mean	0.26✓	0.47✓	0.67✓	0.80✓	0.85✓
	RMS	4.14	6.23	7.92	9.25	10.34
850hPa relative humidity (%)	mean	1.17=	2.37✓	3.15✓	3.51✓	3.59✓
	RMS	9.10	12.75	15.31	17.07	18.66✓

TABLE 1

Verification against Analysis for 15th-26th October for Whole Globe

OP Run Error Statistics

✓ indicates error smaller than for NI run. = indicates errors equal.

		T+24	T+48	T+72	T+96	T+120
MSLP (hPa)	mean	-0.01	-0.01	-0.02	-0.01=	-0.02
	RMS	2.03	3.21	4.34	5.29	6.12✓
500hPa height (dam)	mean	-0.43	-0.67	-0.80	-0.86=	-0.91=
	RMS	1.64=	2.90	4.14	5.14✓	6.15✓
500hPa temperature (°C)	mean	-0.25	-0.40	-0.49=	-0.57=	-0.65=
	RMS	0.94=	1.52=	1.97✓	2.37✓	2.81✓
250hPa temperature (°C)	mean	-0.47	-0.86	-1.16	-1.37	-1.54
	RMS	1.18	1.83	2.32	2.70	3.05
850hPa vector wind (knots)	mean	0.22	0.57	0.97	1.26	1.38
	RMS	6.11✓	9.19✓	11.59✓	13.58✓	15.15✓
250hPa vector wind (knots)	mean	-0.01✓	0.08✓	0.33=	0.46	0.50
	RMS	9.78✓	15.65✓	20.34✓	24.43✓	28.57✓
Surface vector wind (knots)	mean	0.28	0.53	0.73	0.87	0.93
	RMS	4.08✓	6.17✓	7.82✓	9.12✓	10.21✓
850hPa relative humidity (%)	mean	1.17=	2.38	3.17	3.57	16.93
	RMS	9.06✓	12.74✓	15.21✓	17.04✓	39.75

TABLE 2

Verification against Analysis for 15th-26th October for Whole Globe

NI Run Error Statistics

✓ indicates error smaller than for OP run. = indicates errors equal.

		T+0	T+24	T+48	T+72	T+96	T+120
MSLP (hPa)	mean	0.10✓	-0.05	-0.17	-0.21	0.02	0.17
	RMS	1.67✓	2.64✓	3.68✓	4.85	5.60✓	6.60✓
500hPa height (dam)	mean	-0.29✓	-0.79=	-1.18	-1.39	-1.26	-1.14
	RMS	1.71✓	2.42	3.33	4.57	5.77	7.17
250hPa height (dam)	mean	-0.98	-2.01✓	-2.82✓	-3.33	-3.52	-3.49
	RMS	2.64=	3.89	5.27	6.91	8.59	10.60
500hPa temperature (°C)	mean	-0.13=	-0.32✓	-0.41✓	-0.49=	-0.74	-0.73=
	RMS	1.05✓	1.50	1.87	2.37	2.86✓	3.55
250hPa temperature (°C)	mean	0.24✓	0.01=	-0.24✓	-0.38✓	-0.50✓	-0.54
	RMS	1.32✓	1.86✓	2.33✓	2.81	3.25	3.61
850hPa wind speed (knots)	mean	-1.47	-0.90	-0.34✓	-0.19✓	0.02✓	-0.11
	RMS	5.30	7.15	8.15	9.16	9.78	10.50
850hPa wind direction (degrees)	mean	-2.43	-2.31✓	-1.57	-1.24✓	0.37✓	0.76
	RMS	17.07✓	29.67	36.01	45.67	50.96	58.77
250hPa wind speed (knots)	mean	-2.54✓	-3.14✓	-3.20✓	-3.18✓	-3.09✓	-3.01✓
	RMS	7.97✓	11.52	14.21	17.18	19.43✓	22.43✓
250hPa wind direction (degrees)	mean	0.15✓	0.21✓	0.24	1.33✓	1.51✓	2.03✓
	RMS	10.14✓	16.85✓	23.36	29.67✓	36.91	42.81
Surface wind speed (knots)	mean	-0.02✓	0.37	0.71	0.91✓	0.45✓	0.37✓
	RMS	5.47✓	6.06	6.42	6.75	6.81✓	7.01✓
Surface wind direction (degrees)	mean	-1.61✓	-1.38✓	-0.80✓	-1.27	-1.58✓	-2.44
	RMS	25.55✓	33.10✓	41.45	48.58	55.15	63.72
850hPa relative humidity (%)	mean	0.18	1.49	2.27✓	2.79✓	4.11	4.17
	RMS	13.06✓	17.88✓	19.53	21.17	23.54	24.82

TABLE 3

Verification against Observations for 15th-26th October for Whole Globe

OP Run Error Statistics

✓ indicates error smaller than for NI run. = indicates errors equal.

		T+0	T+24	T+48	T+72	T+96	T+120
MSLP (hPa)	mean	0.13	-0.03✓	-0.14✓	-0.17✓	0.01✓	0.11✓
	RMS	1.70	2.67	3.71	4.82✓	5.89	6.83
500hPa height (dam)	mean	-0.30	-0.79=	-1.14✓	-1.31✓	-1.21✓	-0.98✓
	RMS	1.72	2.41✓	3.30✓	4.54✓	5.57✓	6.89✓
250hPa height (dam)	mean	-0.96✓	-2.02	-2.83	-3.31✓	-3.50✓	-3.50✓
	RMS	2.64=	3.88✓	5.24✓	6.83✓	8.47✓	10.19✓
500hPa temperature (°C)	mean	-0.13=	-0.33	-0.43	-0.49=	-0.60✓	-0.73=
	RMS	1.06	1.49✓	1.86✓	2.35✓	2.87	3.45✓
250hPa temperature (°C)	mean	0.25	-0.01=	-0.28	-0.44	-0.51	-0.52✓
	RMS	1.33	1.88	2.35	2.80✓	3.20✓	3.58✓
850hPa wind speed (knots)	mean	-1.46✓	-0.87✓	-0.37	-0.15	-0.09	-0.09✓
	RMS	5.29✓	7.08✓	8.04✓	9.09✓	9.62✓	10.29✓
850hPa wind direction (degrees)	mean	-2.41✓	-2.45	-1.51✓	-1.64	-1.24	-0.39✓
	RMS	17.57	28.53✓	34.62✓	44.27✓	48.84✓	56.50✓
250hPa wind speed (knots)	mean	-2.61	-3.19	-3.29	-3.30	-3.59	-3.80
	RMS	8.01	11.44✓	14.07✓	16.96✓	20.19	22.49
250hPa wind direction (degrees)	mean	0.18	0.22	0.19✓	1.45	2.96	2.75
	RMS	10.16	16.97	23.02✓	29.73	36.43✓	42.29✓
Surface wind speed (knots)	mean	-0.05	0.34✓	0.68✓	0.92	0.94	0.94
	RMS	5.50	6.04✓	6.38✓	6.71✓	6.99	7.14
Surface wind direction (degrees)	mean	-1.76	-1.42	-0.91	-0.70✓	-1.86	-1.42✓
	RMS	26.14	33.62	41.42✓	48.35✓	54.52✓	61.71✓
850hPa relative humidity (%)	mean	0.15✓	1.48✓	2.28	2.81	2.49✓	2.50✓
	RMS	13.09	17.90	19.52✓	21.14✓	22.60✓	24.23✓

TABLE 4

Verification against Observations for 15th-26th October for Whole Globe

NI Run Error Statistics

✓ indicates error smaller than for OP run. = indicates errors equal.

	Mean O-B (hPa)		RMS O-B (hPa)		No. of observations	
Latitude	OP	NI	OP	NI	OP	NI
30-90° S	-0.36	-0.35✓	1.72	1.68✓	1423	1414
30°N-30°S	-0.02✓	-0.06	1.52✓	1.53	11209	11210
30-90°N	-0.05✓	-0.07	1.58	1.57✓	19032	19032
Globe	-0.05✓	-0.07	1.56✓	1.57	31664	31656

TABLE 5
Observation minus Background Statistics for Ship Pressures
✓ indicates the smaller error. = indicates errors equal.

Mean O,B (m/s)	Mean O-B speed (m/s)		RMS O-B vector (m/s)		No. of observations	
	OP	NI	OP	NI	OP	NI
0-3	-0.26	-0.24✓	-	-	2795	2809
3-10	1.07✓	1.12	4.59✓	4.60	22799	22835
10-15	3.00✓	3.11	6.44✓	6.57	5573	5530
15-20	5.24✓	5.45	8.77✓	9.06	828	811
20-25	10.53✓	11.13	13.58✓	14.18	72	66
25-30	19.12✓	19.48	20.41✓	20.73	7	7
All speeds	1.4✓	1.5	5.2=	5.2=	32074	32058

TABLE 6
Observation minus Background Statistics for All Ship Winds
✓ indicates the smaller error. = indicates errors equal.

	Mean O-B (m/s)		RMS O-B vector (m/s)		No. of observations		Percentage flagged	
Latitude	OP	NI	OP	NI	OP	NI	OP	NI
20-90°S	1.5=	1.5=	5.2✓	5.3	552	552	1.8	2.4
30°N-30°S	0.9✓	1.0	4.1=	4.1=	5236	5235	0.9	0.9
30-90°N	1.0✓	1.1	4.7=	4.7=	9020	9019	1.6	1.8
Globe	1.0✓	1.1	4.5=	4.5=	14808	14806	1.3	1.5

TABLE 7
Observation minus Background Statistics for "Good" Ships
✓ indicates the smaller error. = indicates errors equal.

Mean O,B (m/s)	Mean O-B (m/s)		RMS O-B vector (m/s)		No. of observations	
	OP	NI	OP	NI	OP	NI
30-40	1.2✓	1.3	7.5	7.2✓	1511	1503
40-50	0.7✓	1.2	7.7	7.6✓	880	874
50-60	1.5✓	2.1	9.1=	9.1=	520	513
60-70	1.7=	1.7=	8.8	8.7✓	268	261
70-80	4.3✓	4.9	11.1✓	11.4	19	94
>80	3.5✓	4.6	9.8✓	10.6	7	17
All speeds	0.8✓	1.0	7.5=	7.5=	8542	8501

TABLE 8

Observation minus Background Statistics for Airep Winds for Area 2 for Higher Speeds

✓ indicates the smaller error. = indicates errors equal.

Mean O,B (m/s)	Mean O-B (m/s)		RMS O-B vector (m/s)		No. of observations	
	OP	NI	OP	NI	OP	NI
30-40	1.0✓	1.1	7.6	7.4✓	6125	6106
40-50	1.3✓	1.6	7.9	7.8✓	3804	3830
50-60	1.6✓	2.0	9.1	9.0✓	2196	2180
60-70	1.8✓	2.1	9.2=	9.2=	1436	1437
70-80	3.0✓	3.3	9.3✓	9.4	669	648
>80	3.7✓	4.6	9.6✓	9.9	124	122
All speeds	0.9✓	1.0	7.2=	7.2=	35553	35457

TABLE 9

Observation minus Background Statistics for Airep Winds for all Areas for Higher Speeds

✓ indicates the smaller error. = indicates errors equal.

Area Number	Mean O-B (m/s)		RMS O-B vector(m/s)		No.of observations	
	OP	NI	OP	NI	OP	NI
1	1.3✓	1.4	7.1=	7.1=	2572	2566
2	0.8✓	1.0	7.5=	7.5=	8542	8501
3	1.0✓	1.1	6.5=	6.5=	11920	1913
4	0.7✓	0.9	7.9	7.8✓	9893	9856
5	0.9✓	1.0	7.0=	7.0=	2626	2621

TABLE 10

Observation minus Background Statistics for Airep Winds for all Speeds Combined

✓ indicates the smaller error. = indicates errors equal.

Mean O,B (m/s)	Mean O-B (m/s)		RMS O-B vector (m/s)		No. observations		Number flagged	
	OP	NI	OP	NI	OP	NI	OP	NI
30-40	1.0✓	1.1	8.6✓	9.3	16695	16753	138	367
40-50	1.6✓	1.8	9.5✓	10.3	9934	9937	92	222
50-60	2.1✓	2.6	10.5✓	11.3	4689	4662	56	116
60-70	2.6✓	2.9	11.1✓	12.4	2464	2444	49	87
70-80	3.6✓	4.1	13.6✓	15.7	961	943	18	41
>80	9.9✓	10.5	39.4✓	38.6	172	163	3	6
All speeds	0.7✓	-	8.5✓	8.9	94889	94889	643	1619

TABLE 11

Observation minus Background Statistics for Airep Winds for the Whole Globe and Higher Speeds, no Exclusions

✓ indicates the smaller error. = indicates errors equal.

Level	Mean O-B (°C)		RMS O-B (°C)		No. of observations	
(hPa)	OP	NI	OP	NI	OP	NI
1000-850	0.41=	0.41=	1.54=	1.54=	857	857
700-400	0.17✓	0.20	1.33✓	1.35	1312	1313
300-100	0.16✓	0.17	1.51=	1.51=	1297	1297

TABLE 12

Observation minus Background Statistics for all Tempship Temperatures

✓ indicates the smaller error. = indicates errors equal.

Level	Mean O-B (%)		RMS O-B (%)		No. of observations	
(hPa)	OP	NI	OP	NI	OP	NI
1000-850	-4.6=	-4.6=	18.6=	18.6=	855	855
700-500	-4.9✓	-5.1	24.5=	24.5=	865	865
400-300	=4.1✓	-4.5	23.4	23.3✓	427	427

TABLE 13

Observation minus Background Statistics for all Tempship Humidities

✓ indicates the smaller error. = indicates errors equal.

	T+0	T+24	T+48	T+72	T+96	T+120
Not FC	1	51	60	66	71	75
FC	86	36	27	21	16	12
Mean DPE	106✓	300✓	491✓	753✓	921✓	1230
Mean DX	35	50✓	131=	113✓	258✓	689✓
Mean DY	1✓	-28✓	-167✓	-247✓	-313✓	55✓
Mean AT	-37	-143	-273✓	-403✓	-496✓	-589✓
Mean CT	27✓	-9✓	-80✓	-29✓	118	196

Not FC : No. of forecasts which do not fulfil all the requirements below
FC : No. of forecasts verified fulfilling all the requirements below
1 : Observed maximum sustained wind at least 35 knots at the VT
2 : Forecast TC centre equatorwards of 40 degrees latitude
3 : Forecast TC centre relative vorticity above critical limit for verification
4 : Observation within 6 hours of VT present for verification

Mean DPE : Mean of all forecast direct positional errors
Mean DX : Mean of all forecast positional errors in the east-west direction
Mean DY : Mean of all forecast positional errors in the north-south direction
Mean AT : Mean of all forecast positional errors along the track of the TC
: Positive if forecast position lies ahead of observed position
Mean CT : Mean of all forecast positional errors across the track of the TC
: Positive if forecast position lies right of the observed track in the
: northern and left of track in southern hemisphere.
All errors are in kilometres.

TABLE 14
Tropical Cyclone Positional Errors for all Storms for the OP run
✓ indicates a smaller error than for the NI run. = indicates errors equal

	T+0	T+24	T+48	T+72	T+96	T+120
Not FC	1	66	71	73	76	78
FC	86	21	17	14	11	9
Mean DPE	255	420	696	781	931	1206✓
Mean DX	-8✓	88	131=	246	433	760
Mean DY	2	-106	-261	-277	-320	-347
Mean AT	-34✓	-71✓	-407	-544	-681	-950
Mean CT	-28	-146	-182	-122	66✓	172✓

Key as for Table 14. All errors are in kilometres.

TABLE 15
Tropical Cyclone Positional Errors for all Storms for the NI run
✓ indicates a smaller error than for the OP run. = indicates errors equal

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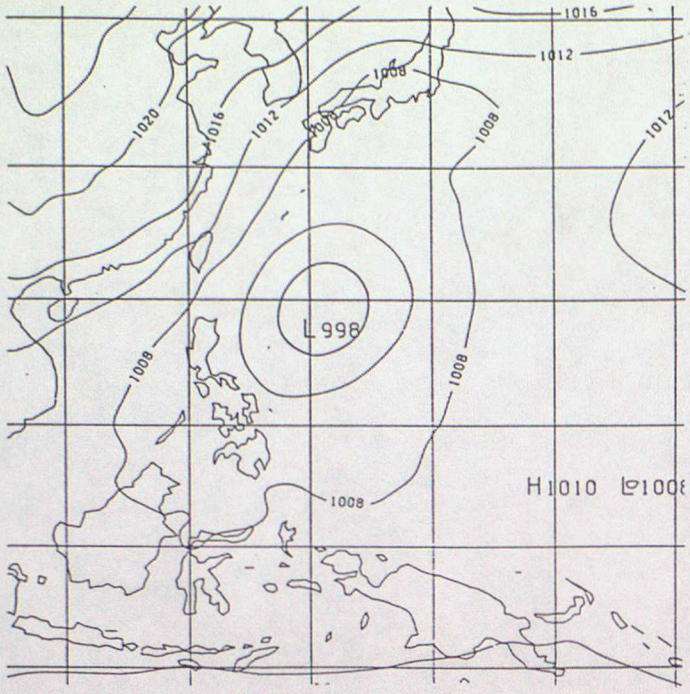
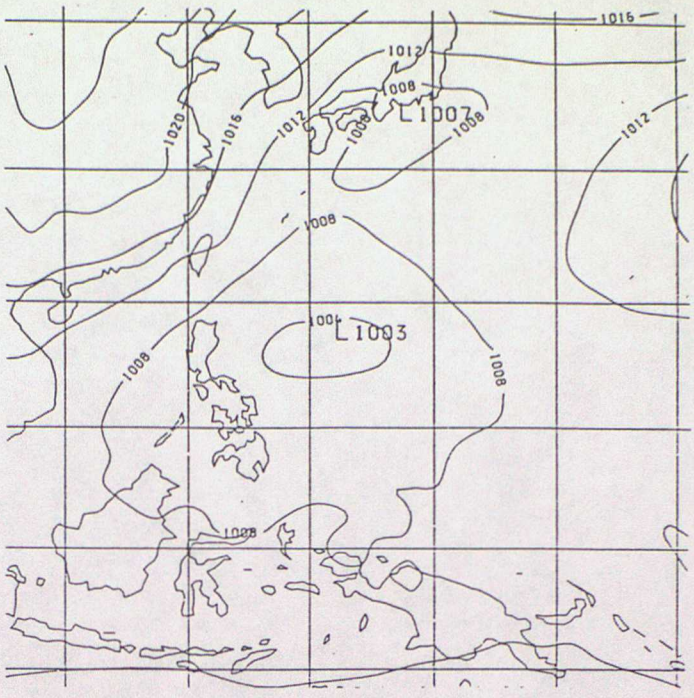
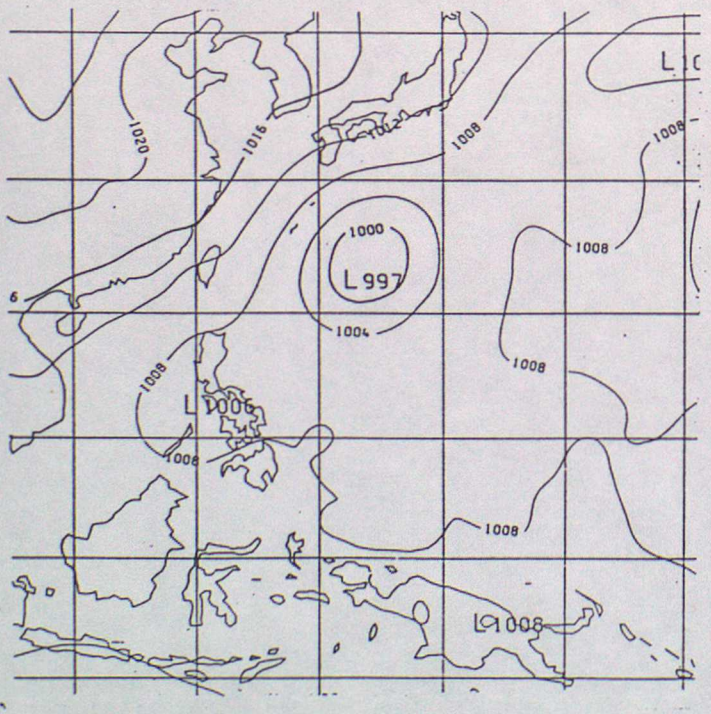


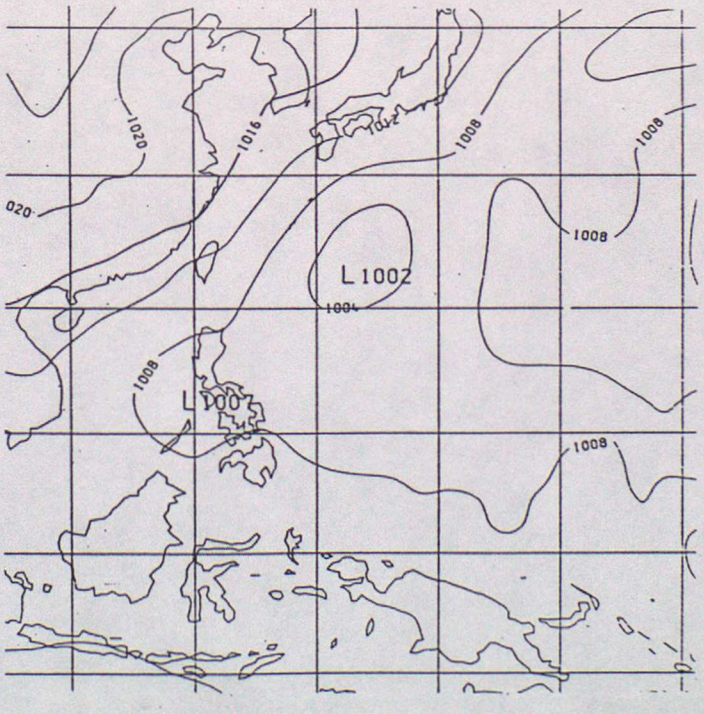
DT 00Z 13.10.92 VT 00Z 16.10.92 T+72
Operational MSLP (hPa)
Figure 1(a)



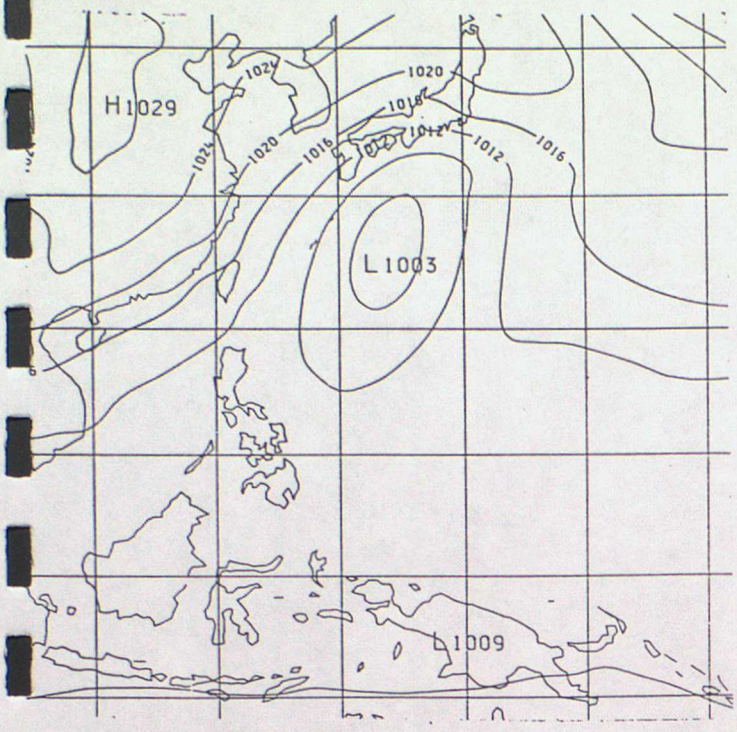
DT 00Z 13.10.92 VT 00Z 16.10.92 T+72
No Intervention MSLP (hPa)
Figure 1(b)



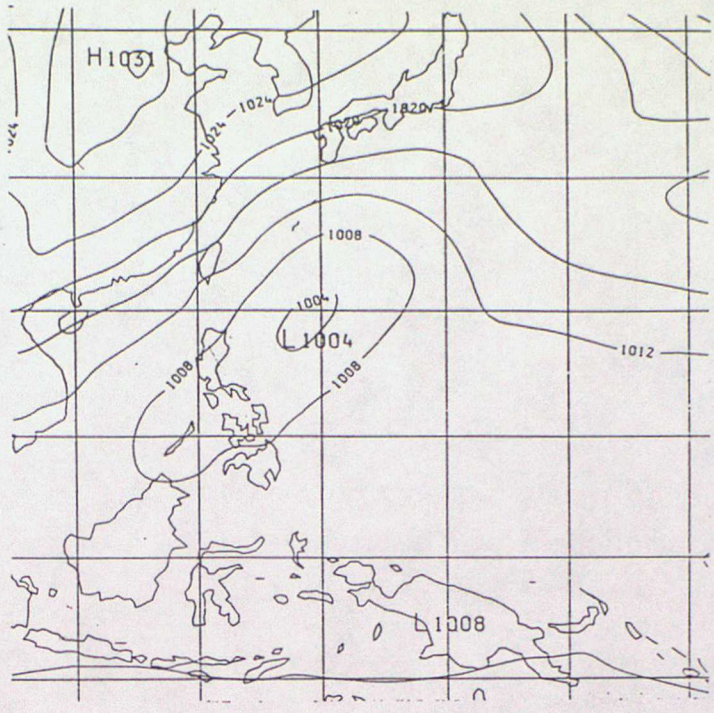
DT 00Z 16.10.92 VT 00Z 16.10.92 T+00
Operational MSLP (hPa)
Figure 1(c)



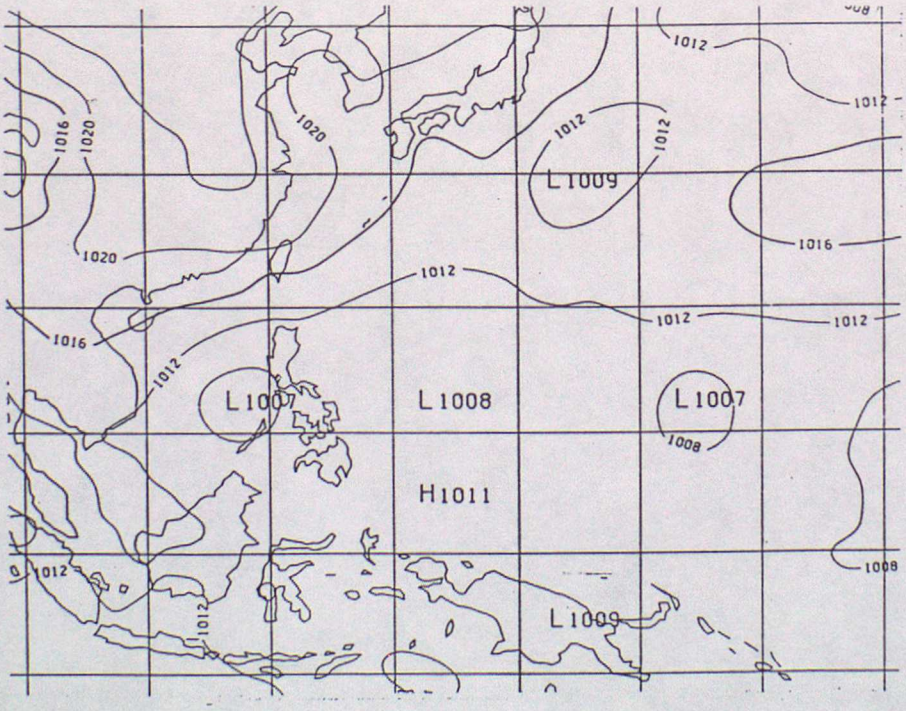
DT 00Z 16.10.92 VT 00Z 16.10.92 T+00
No Intervention MSLP (hPa)
Figure 1(d)



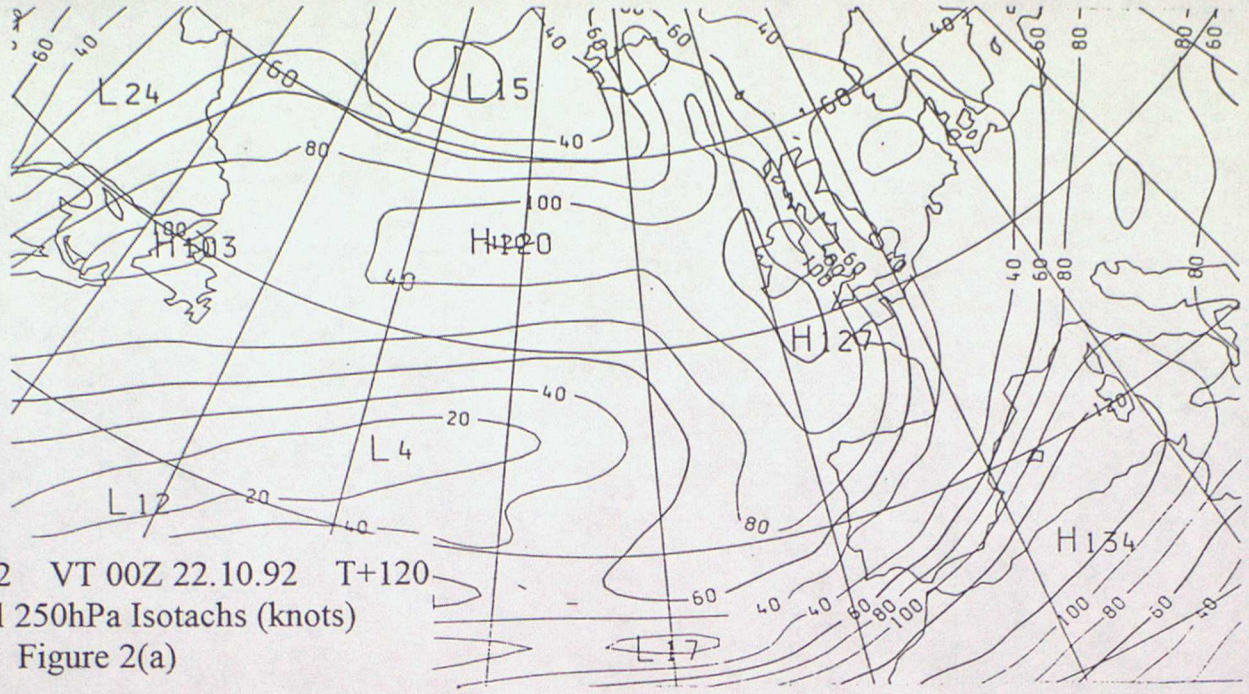
DT 00Z 13.10.92 VT 00Z 18.10.92 T+120
Operational MSLP (hPa)
Figure 1(e)



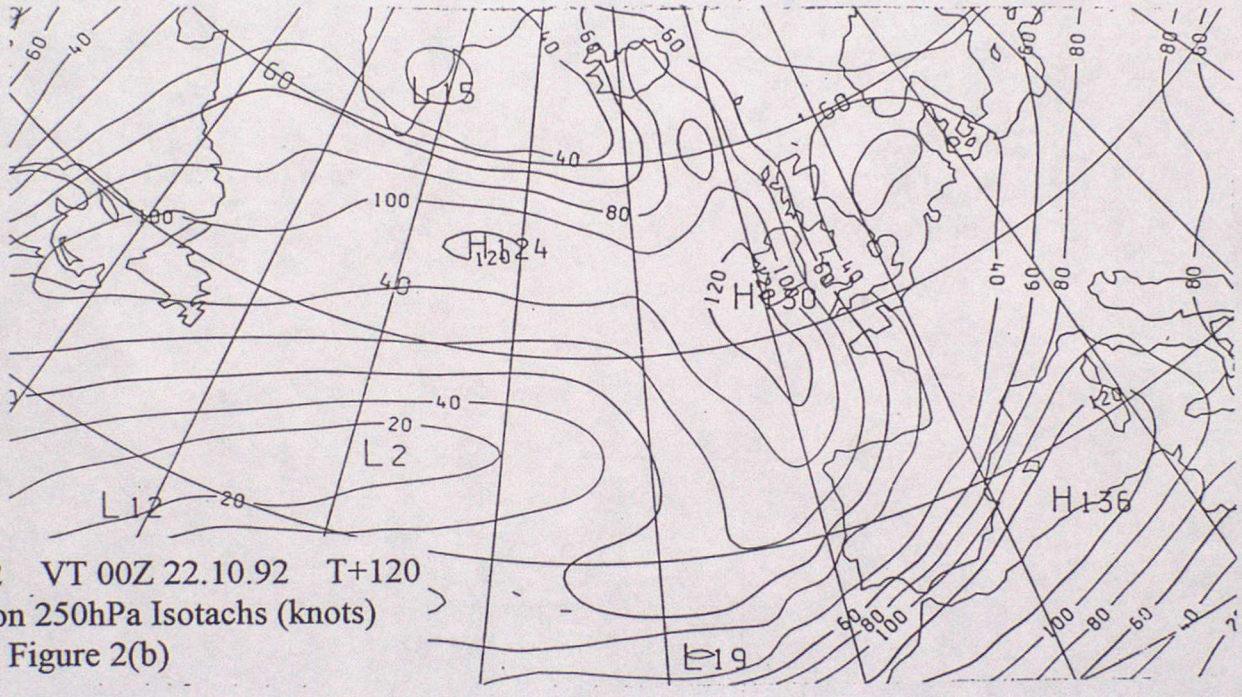
DT 00Z 13.10.92 VT 00Z 18.10.92 T+120
No Intervention MSLP (hPa)
Figure 1(f)



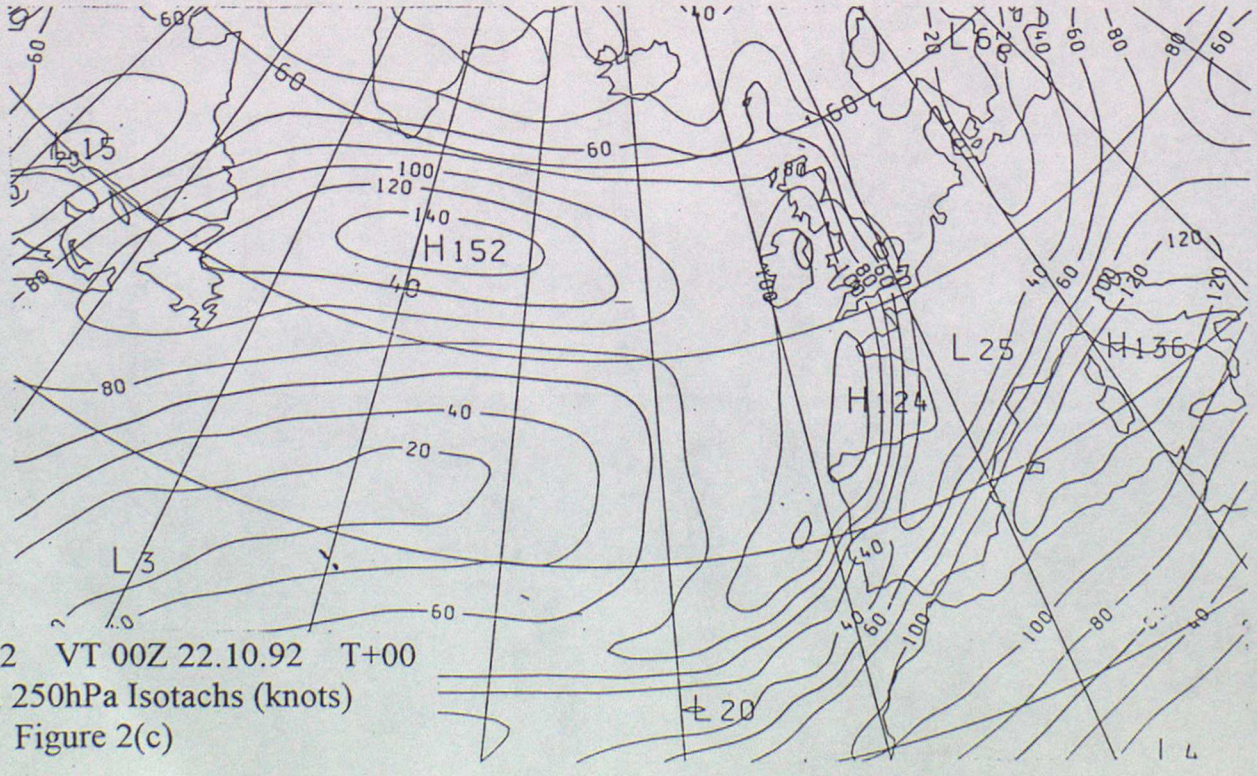
DT 00Z 18.10.92 VT 00Z 18.10.92 T+00
Operational MSLP (hPa)
Figure 1(g)



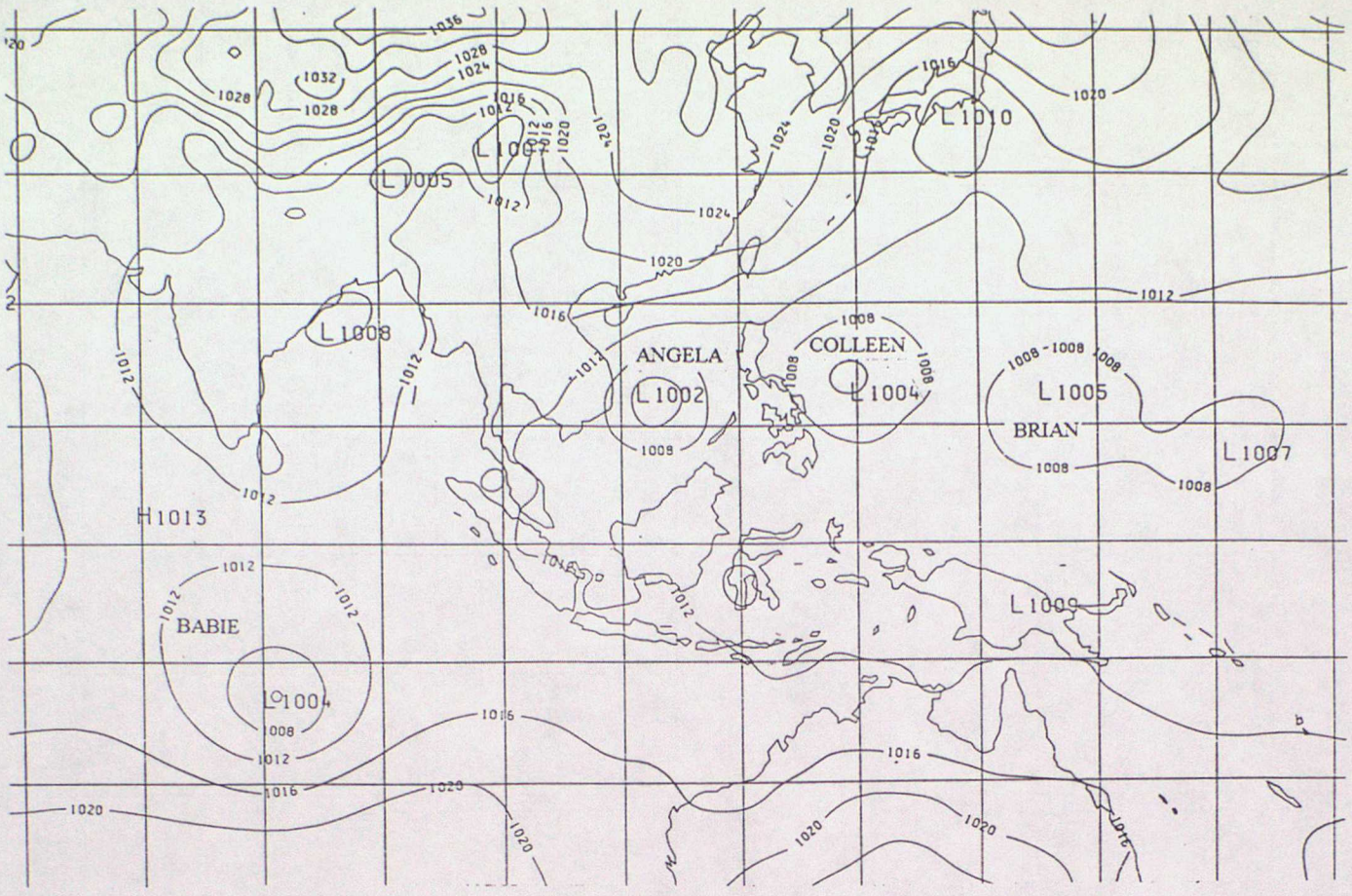
DT 00Z 17.10.92 VT 00Z 22.10.92 T+120
Operational 250hPa Isotachs (knots)
Figure 2(a)



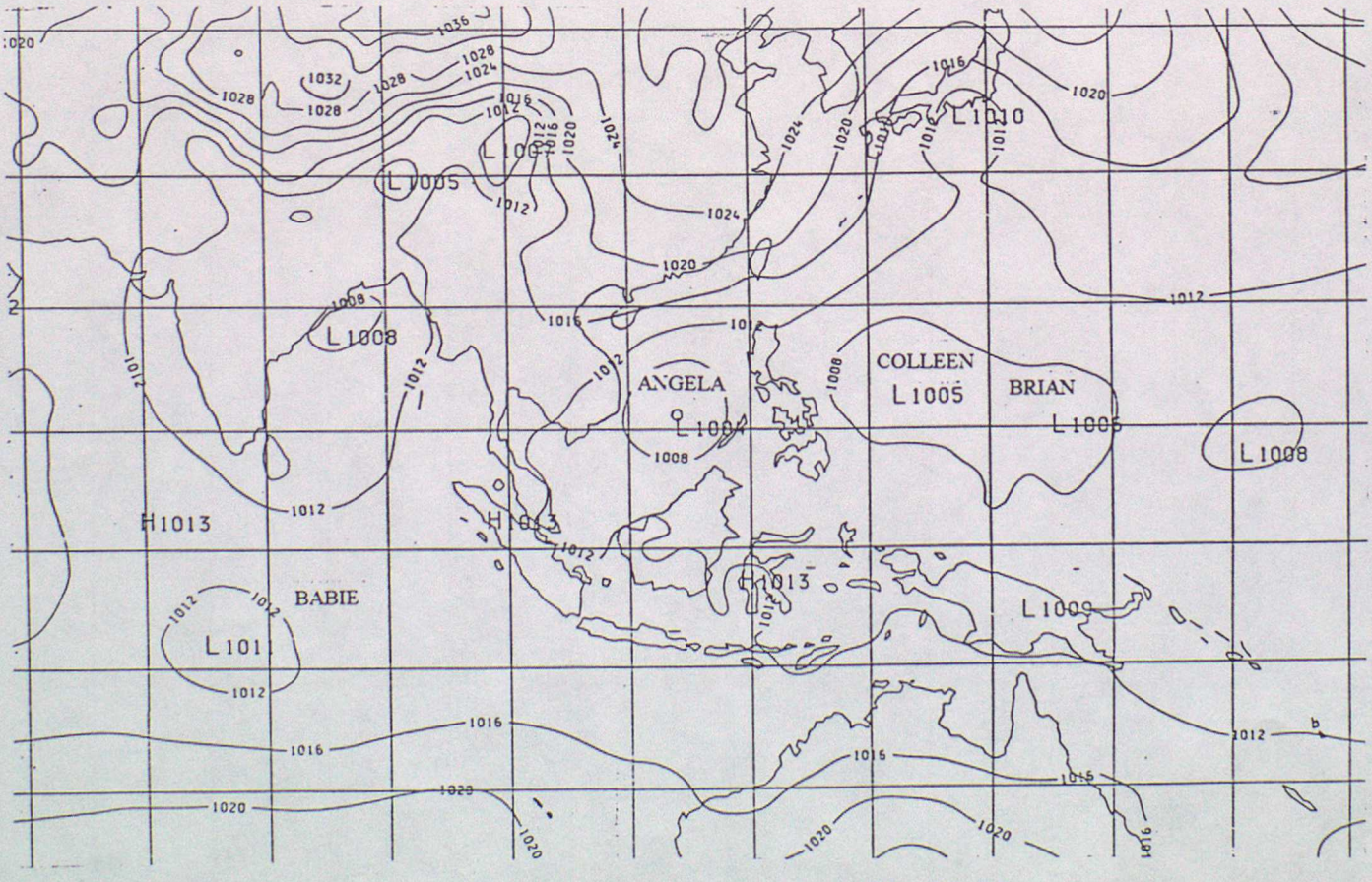
DT 00Z 17.10.92 VT 00Z 22.10.92 T+120
No Intervention 250hPa Isotachs (knots)
Figure 2(b)



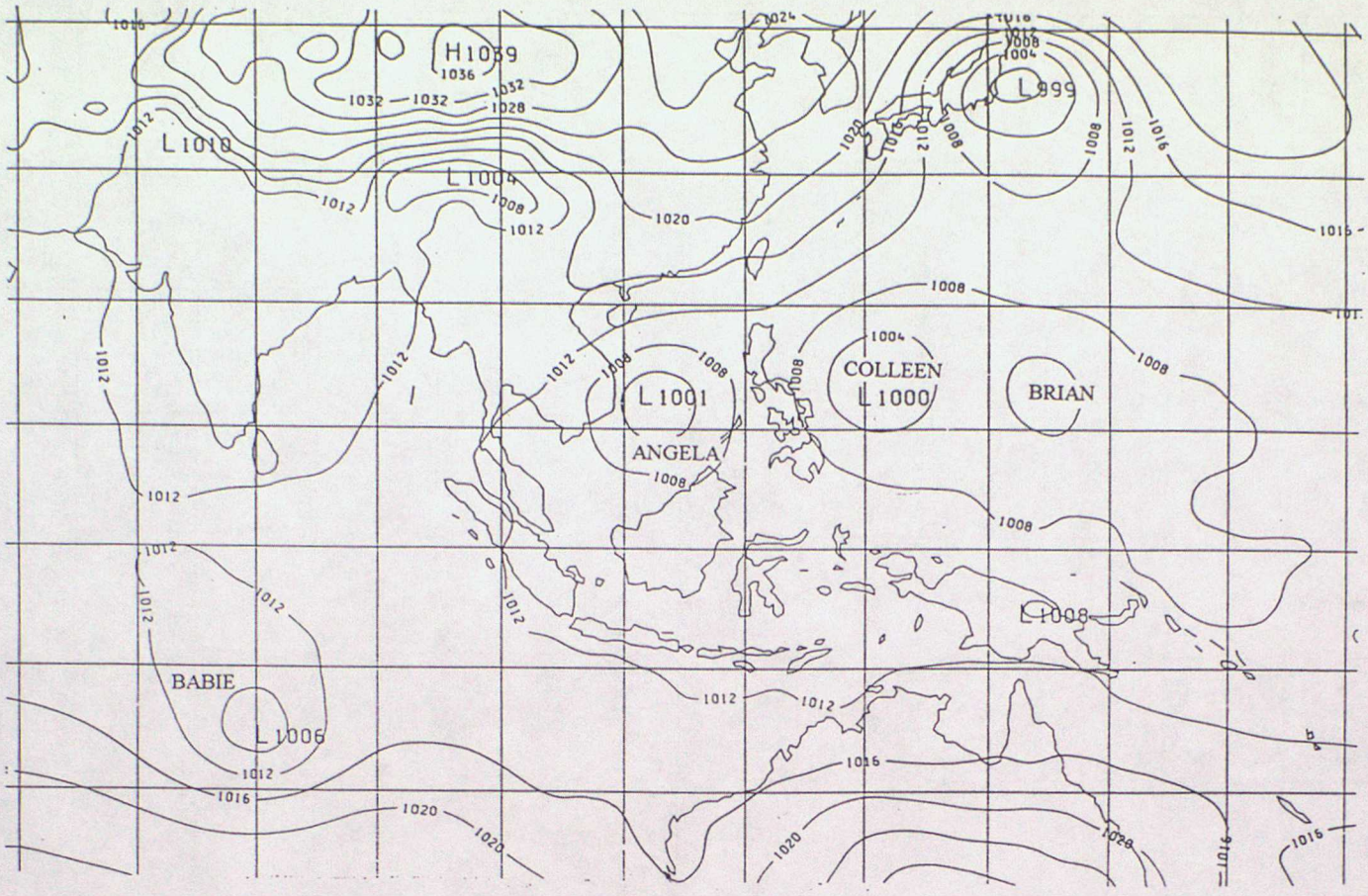
DT 00Z 22.10.92 VT 00Z 22.10.92 T+00
Operational 250hPa Isotachs (knots)
Figure 2(c)



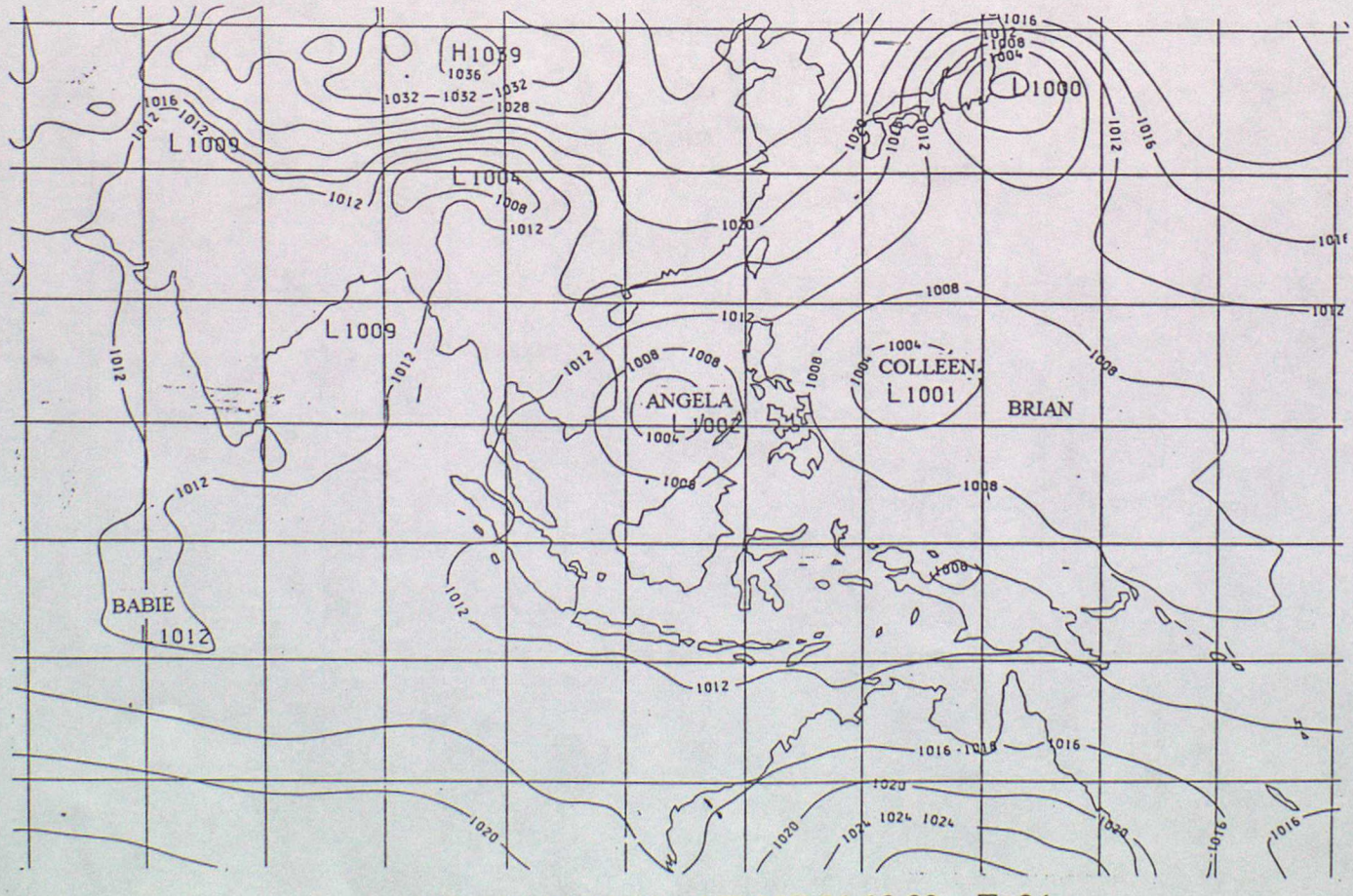
DT 00Z 20.10.92 VT 00Z 20.10.92 T+00
Operational MSLP (hPa)
Figure 3(a)



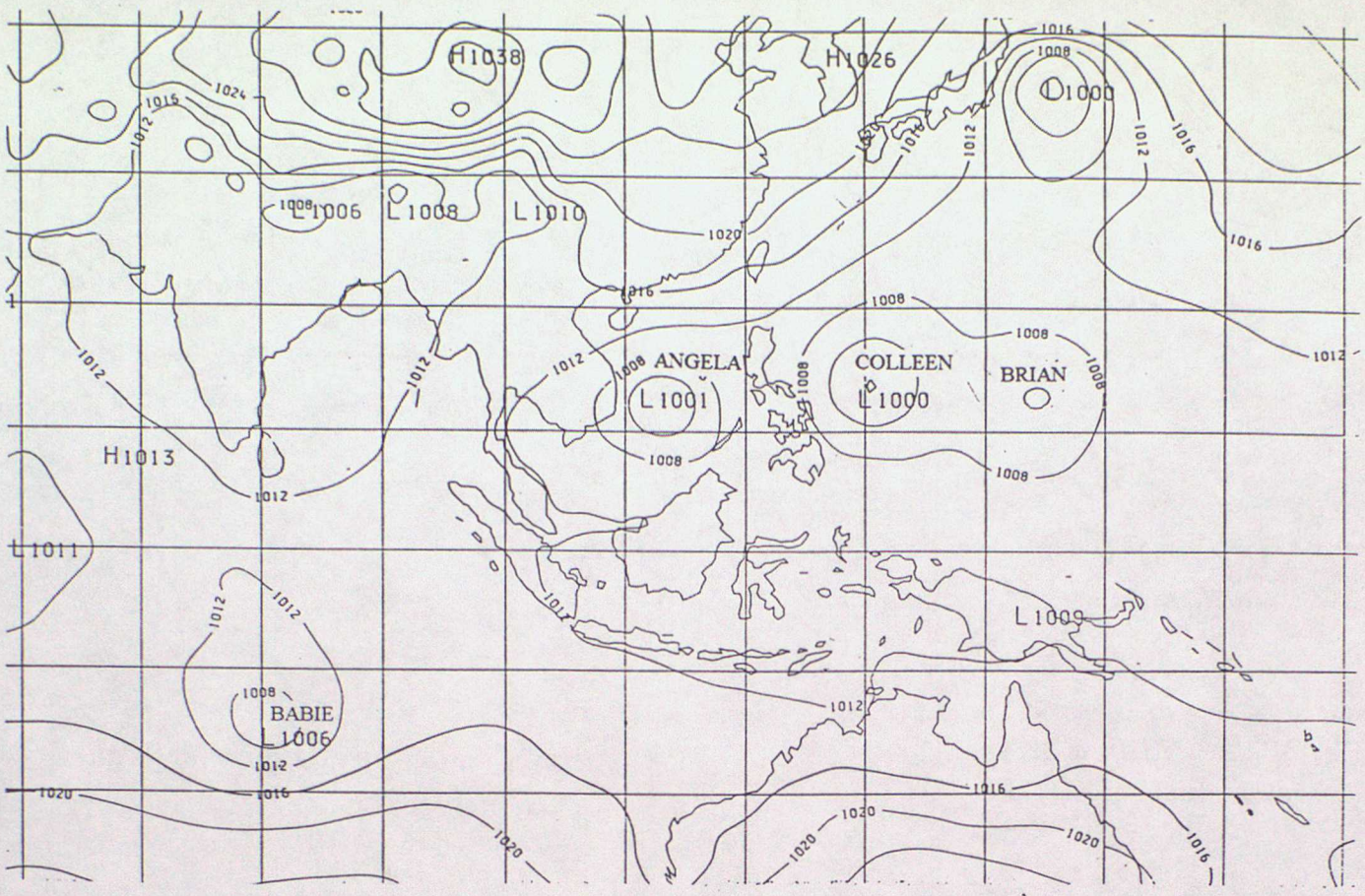
DT 00Z 20.10.92 VT 00Z 20.10.92 T+00
No Intervention MSLP (hPa)
Figure 3(b)



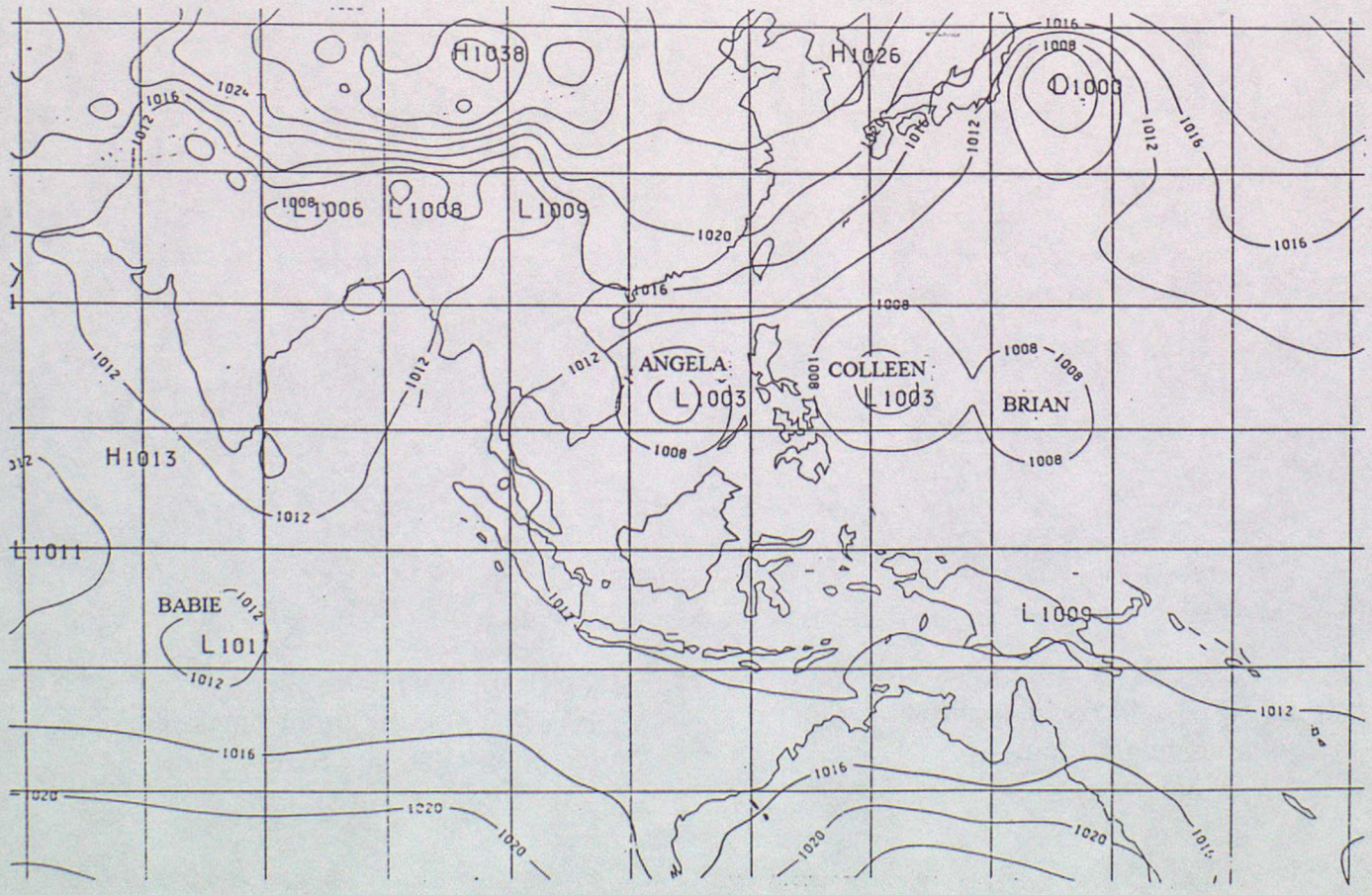
DT 00Z 20.10.92 VT 00Z 21.10.92 T+24
Operational MSLP (hPa)
Figure 3(c)



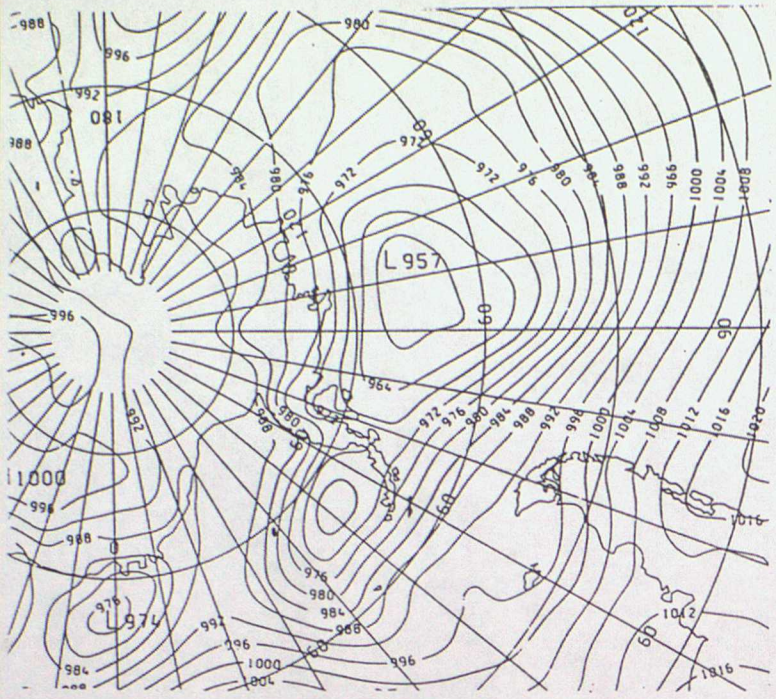
DT 00Z 20.10.92 VT 00Z 21.10.92 T+24
No Intervention MSLP (hPa)
Figure 3(d)



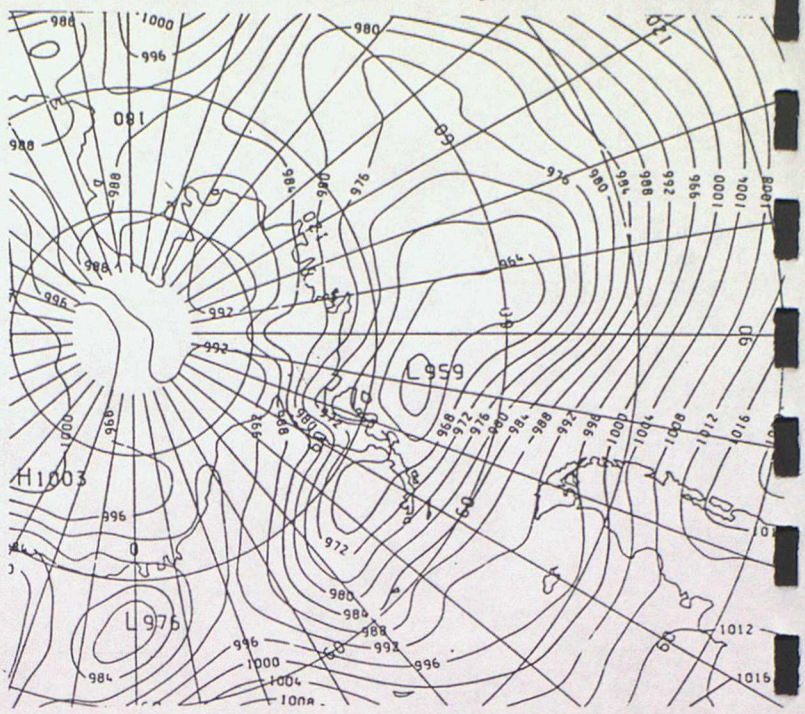
DT 00Z 21.10.92 VT 00Z 21.10.92 T+00
Operational MSLP (hPa)
Figure 3(e)



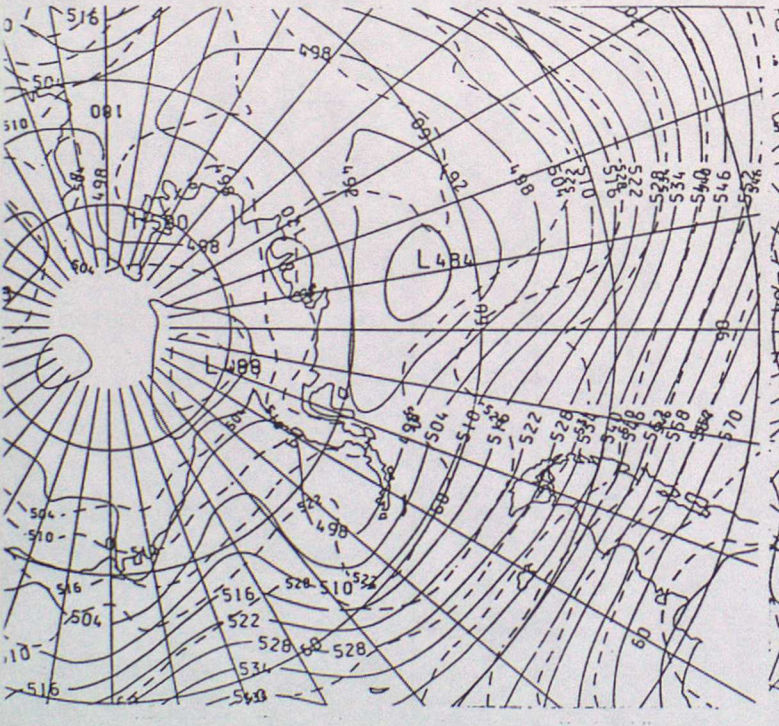
DT 00Z 21.10.92 VT 00Z 21.10.92 T+00
No Intervention MSLP (hPa)
Figure 3(f)



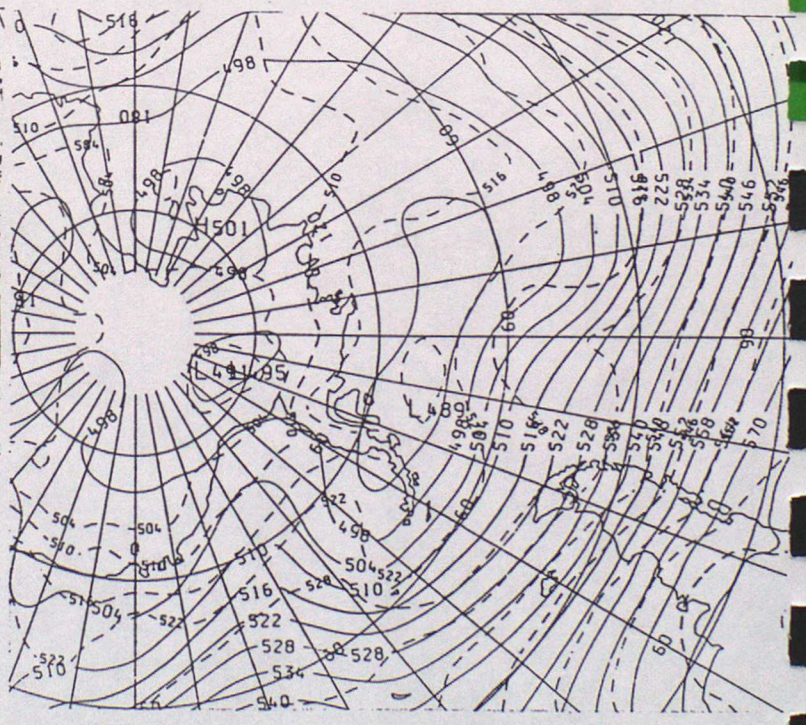
DT 00Z 21.10.92 VT 00Z 22.10.92 T+24
Operational MSLP (hPa)
Figure 4(a)



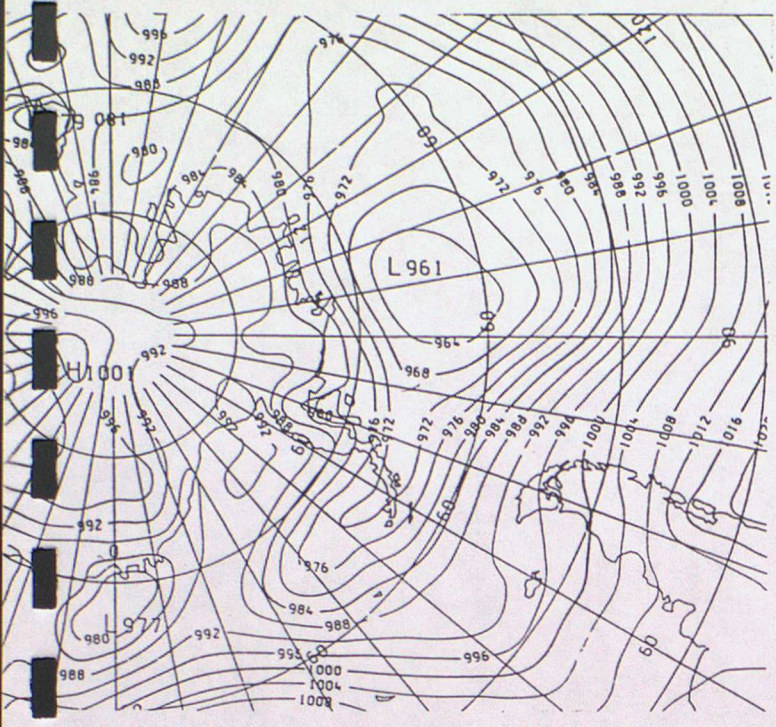
DT 00Z 21.10.92 VT 00Z 22.10.92 T+24
No Intervention MSLP (hPa)
Figure 4(b)



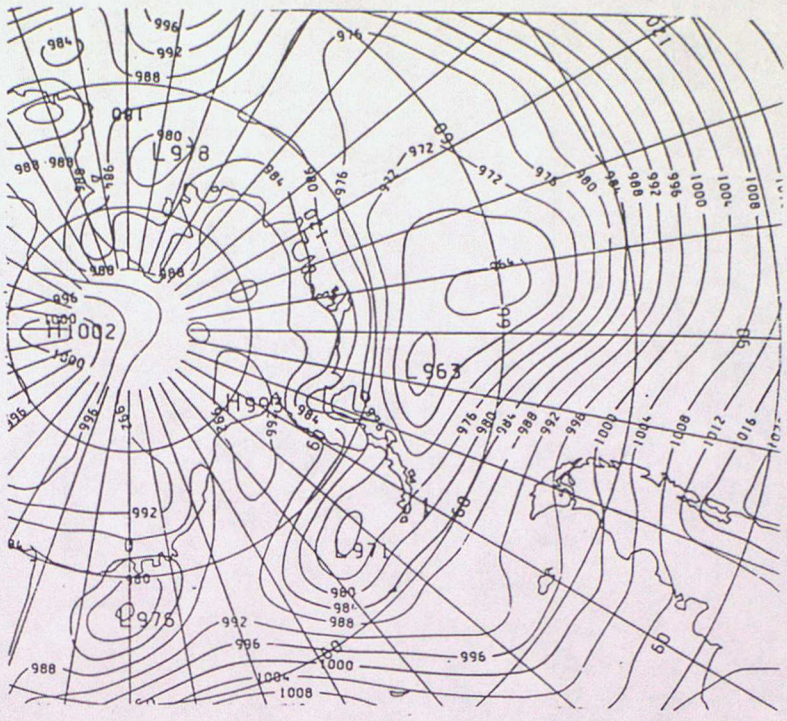
DT 00Z 21.10.92 VT 00Z 22.10.92 T+24
Operational 500-1000hPa Thickness &
500hPa Height (dam)
Figure 4(c)



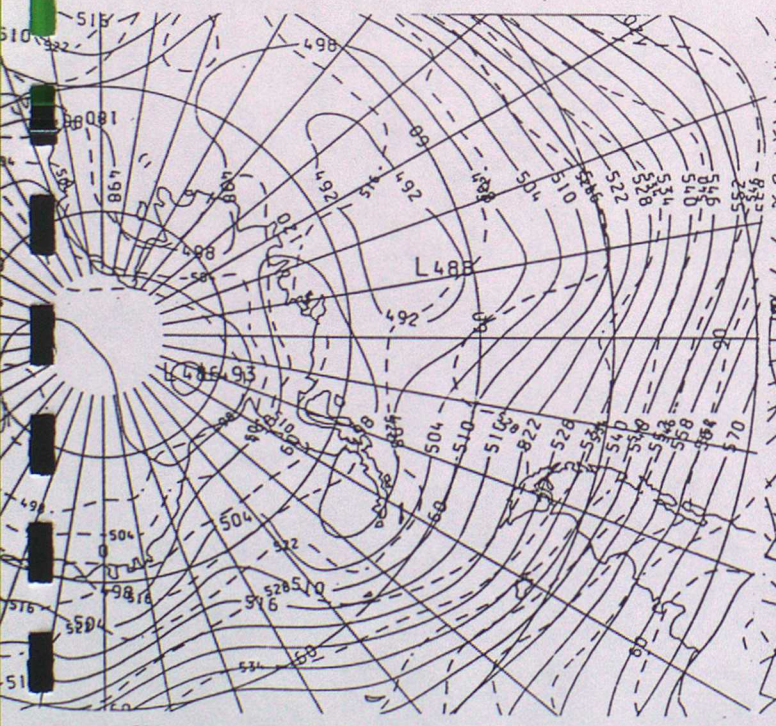
DT 00Z 21.10.92 VT 00Z 22.10.92 T+24
No Intervention 500-1000hPa Thickness &
500hPa Height (dam)
Figure 4(d)



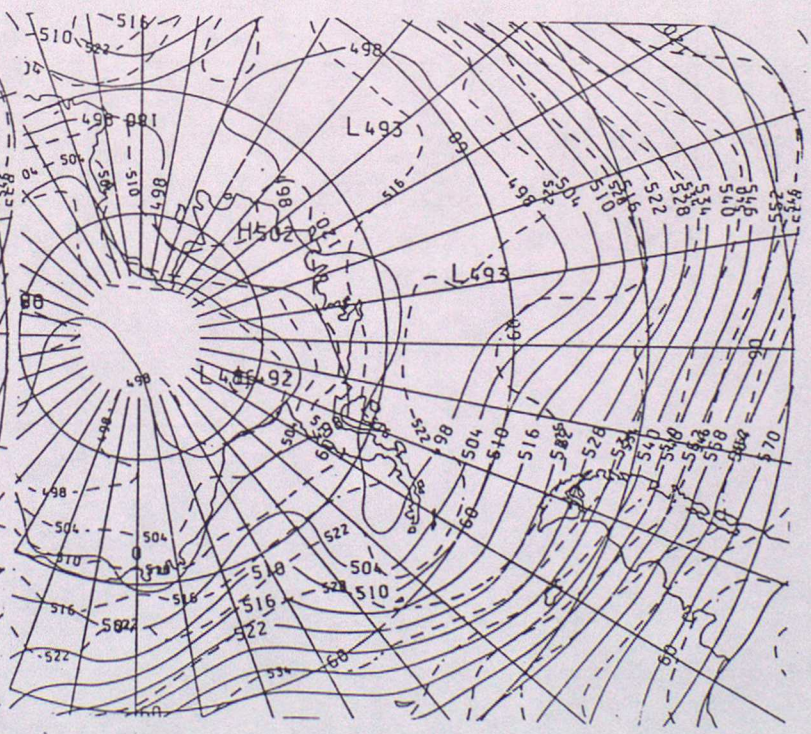
DT 00Z 22.10.92 VT 00Z 22.10.92 T+00
Operational MSLP (hPa)
Figure 4(e)



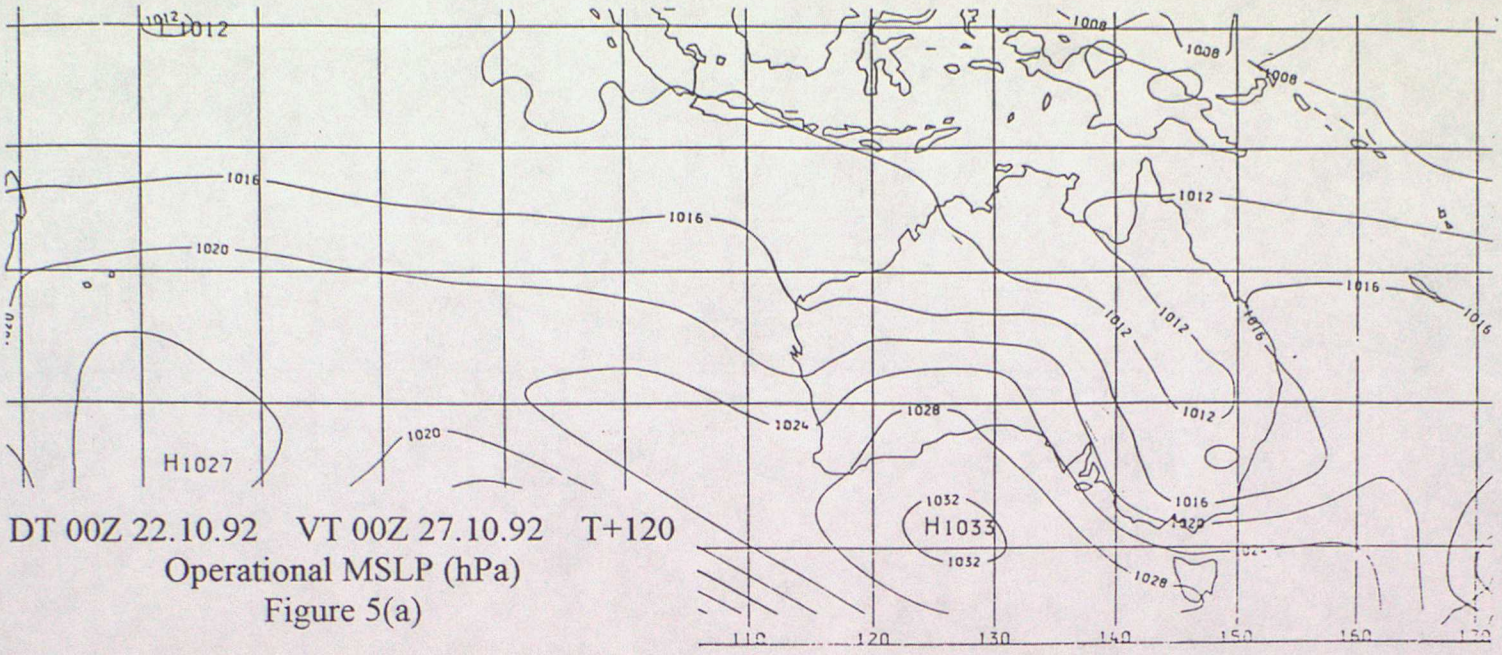
DT 00Z 22.10.92 VT 00Z 22.10.92 T+00
No Intervention MSLP (hPa)
Figure 4(f)



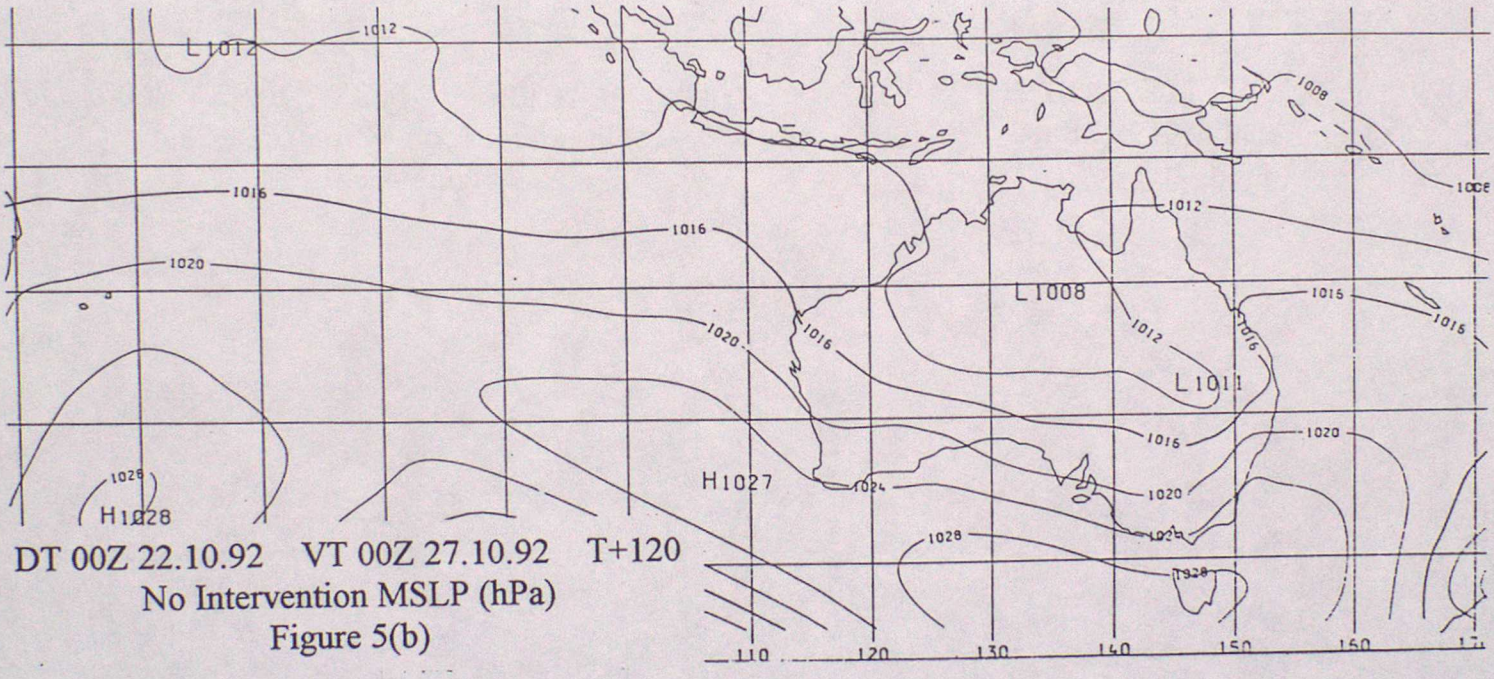
DT 00Z 22.10.92 VT 00Z 22.10.92 T+00
Operational 500-1000hPa Thickness &
500hPa Height (dam)
Figure 4(g)



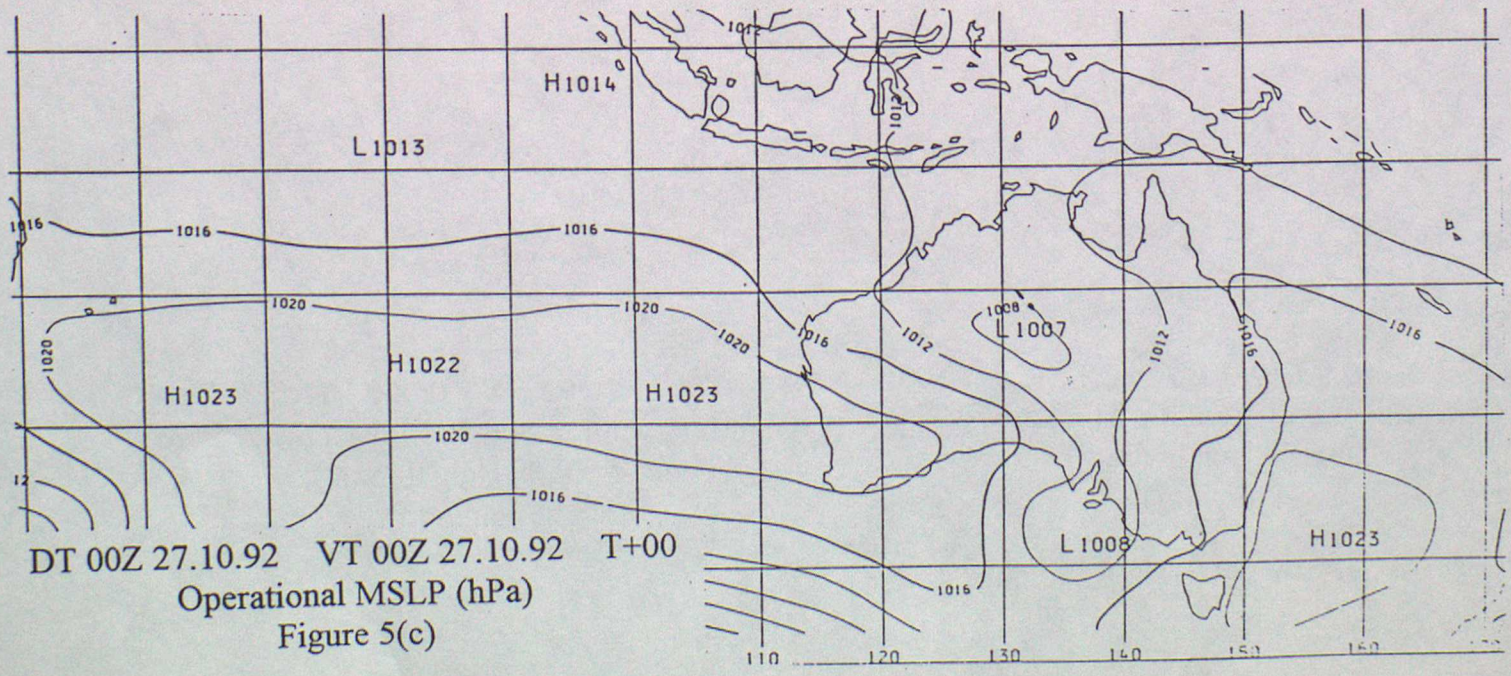
DT 00Z 22.10.92 VT 00Z 22.10.92 T+00
No Intervention 500-1000hPa Thickness &
500hPa Height (dam)
Figure 4(h)



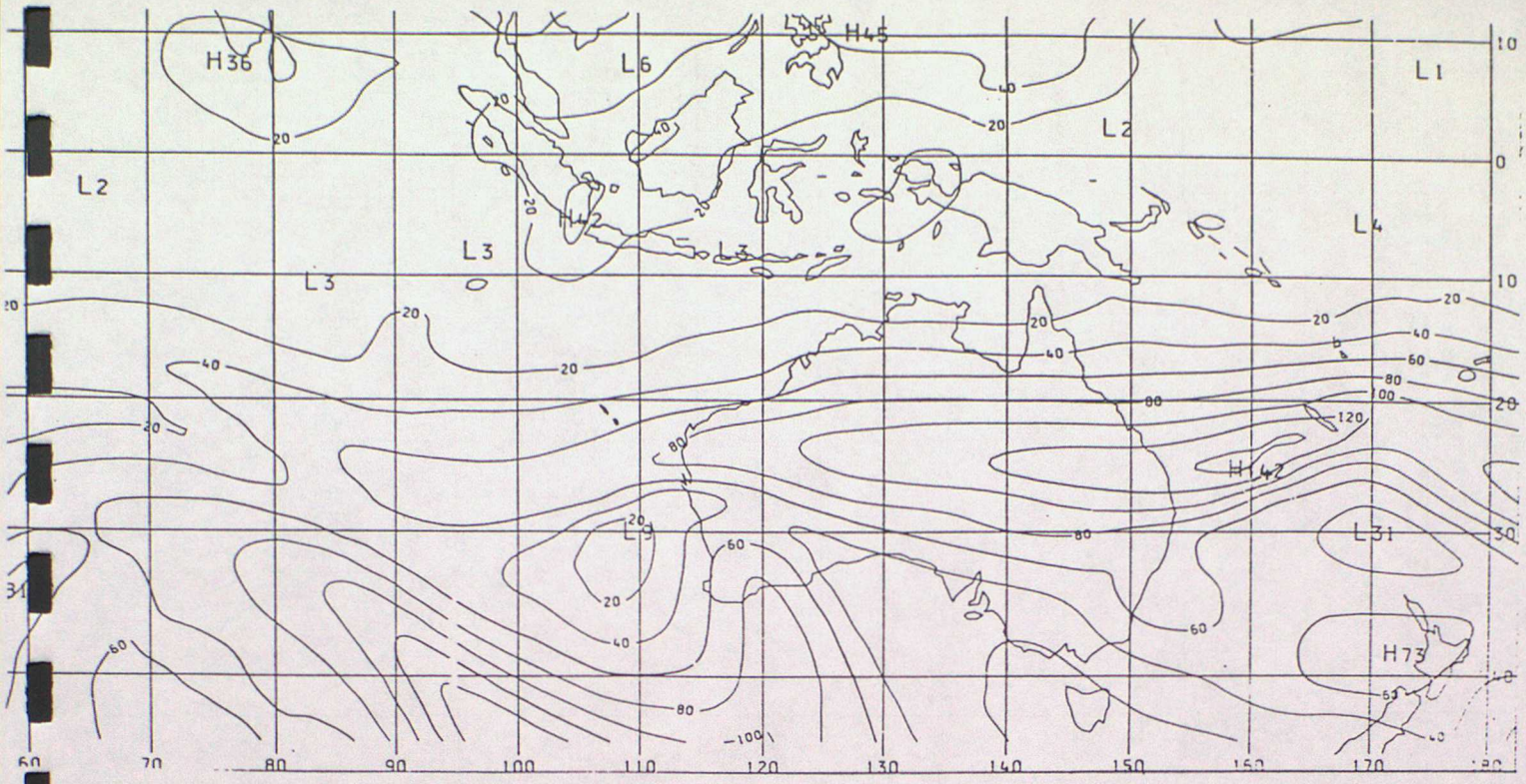
DT 00Z 22.10.92 VT 00Z 27.10.92 T+120
Operational MSLP (hPa)
Figure 5(a)



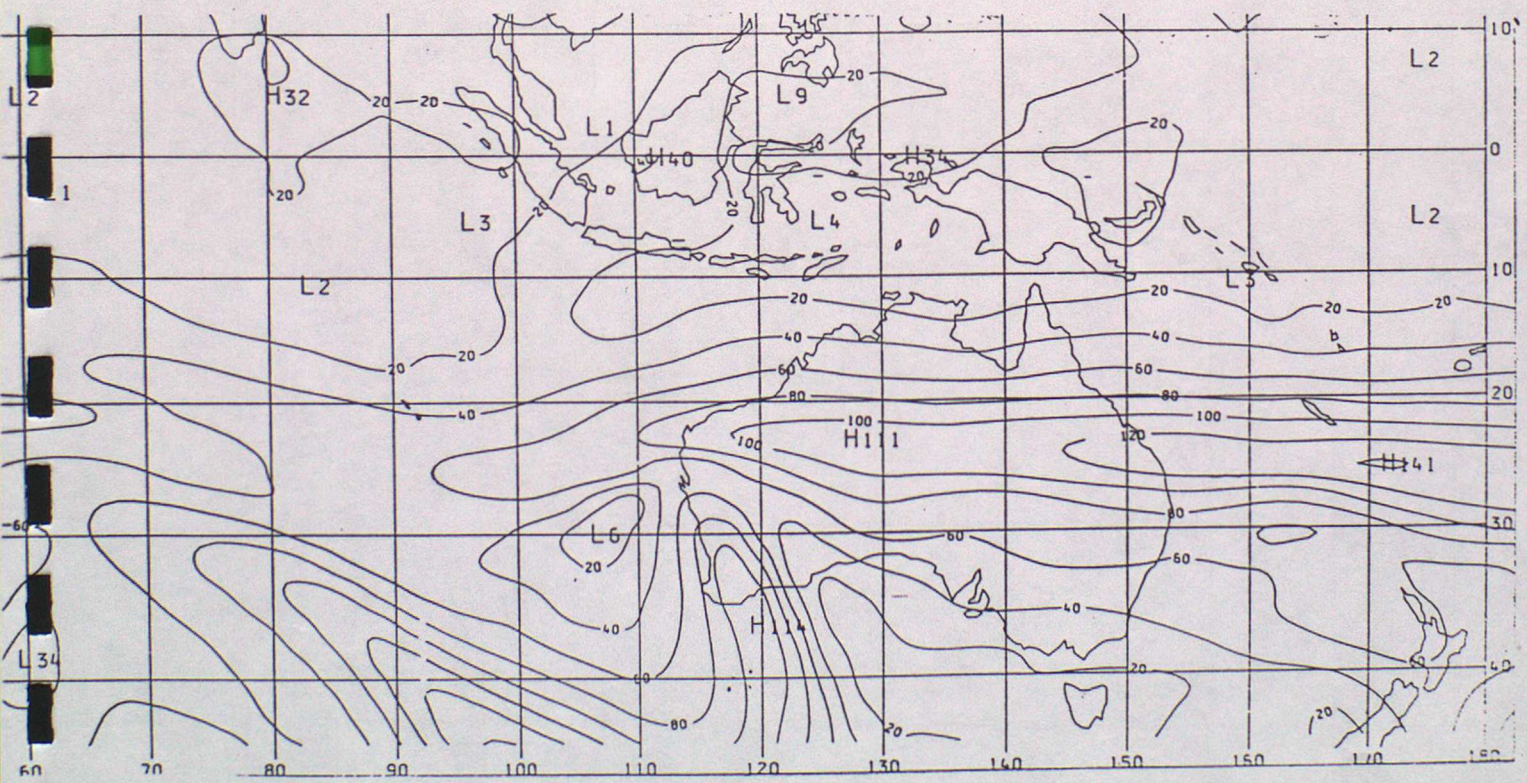
DT 00Z 22.10.92 VT 00Z 27.10.92 T+120
No Intervention MSLP (hPa)
Figure 5(b)



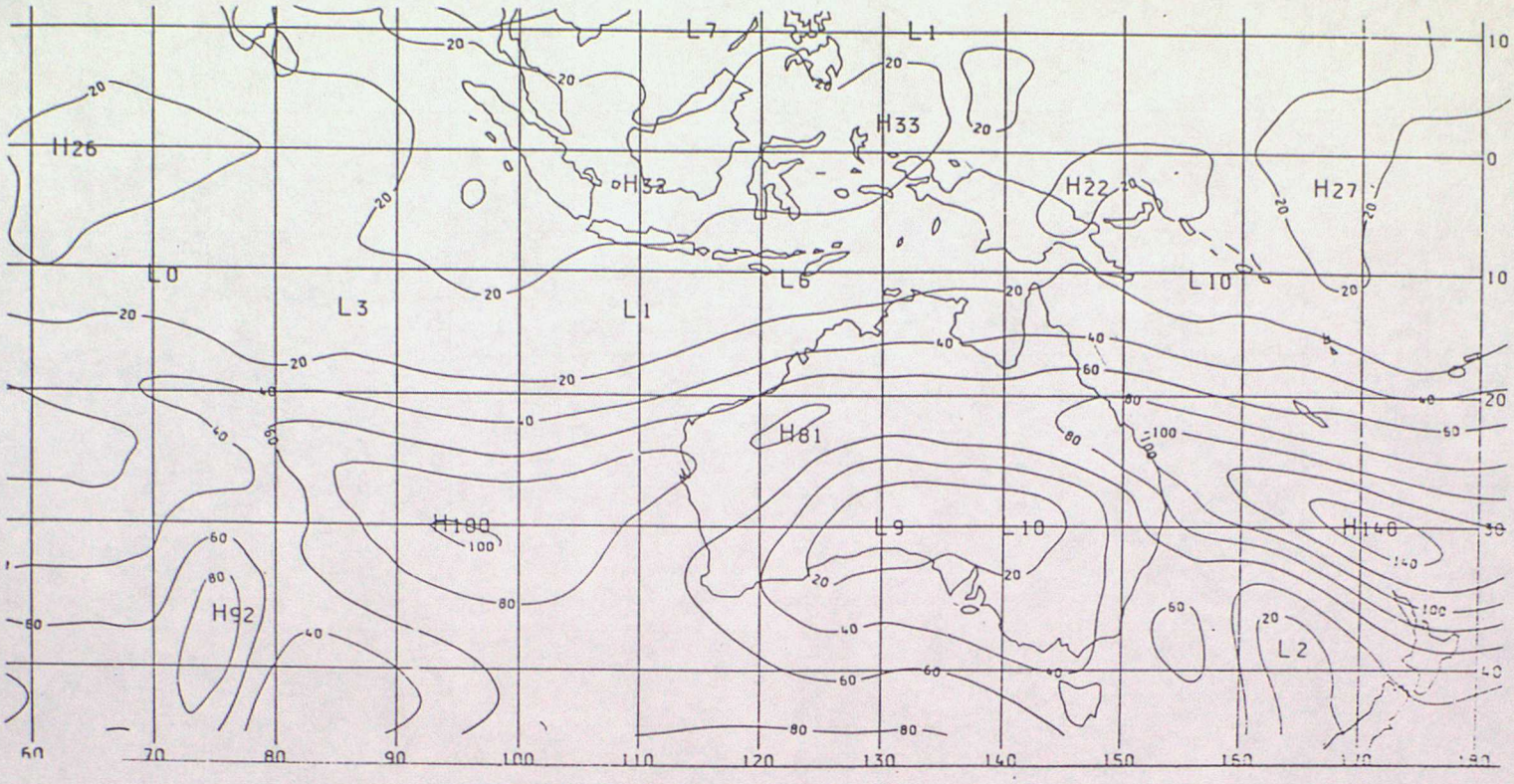
DT 00Z 27.10.92 VT 00Z 27.10.92 T+00
Operational MSLP (hPa)
Figure 5(c)



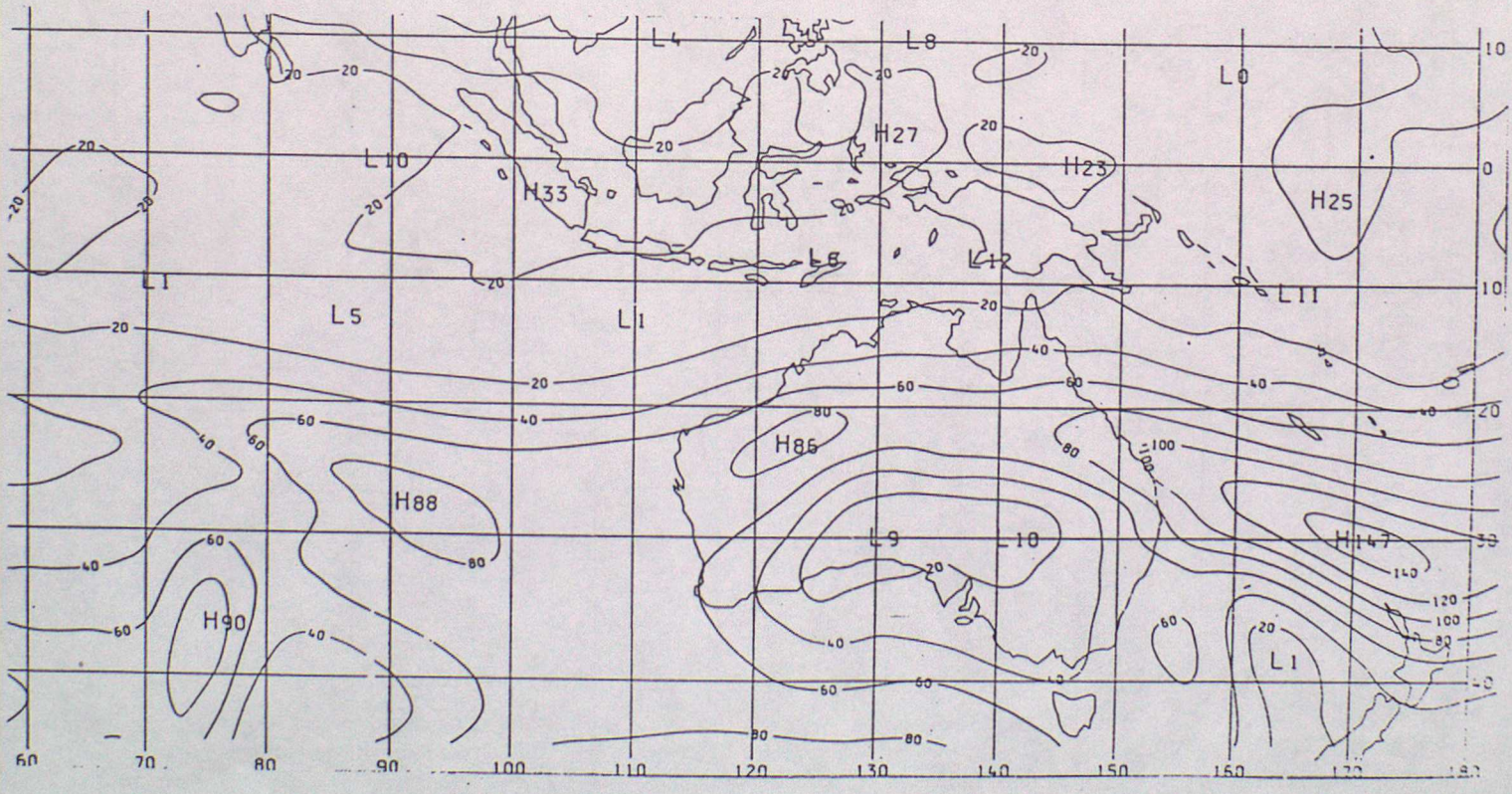
DT 00Z 22.10.92 VT 00Z 27.10.92 T+120
Operational 250hPa Isotachs (knots)
Figure 5(d)



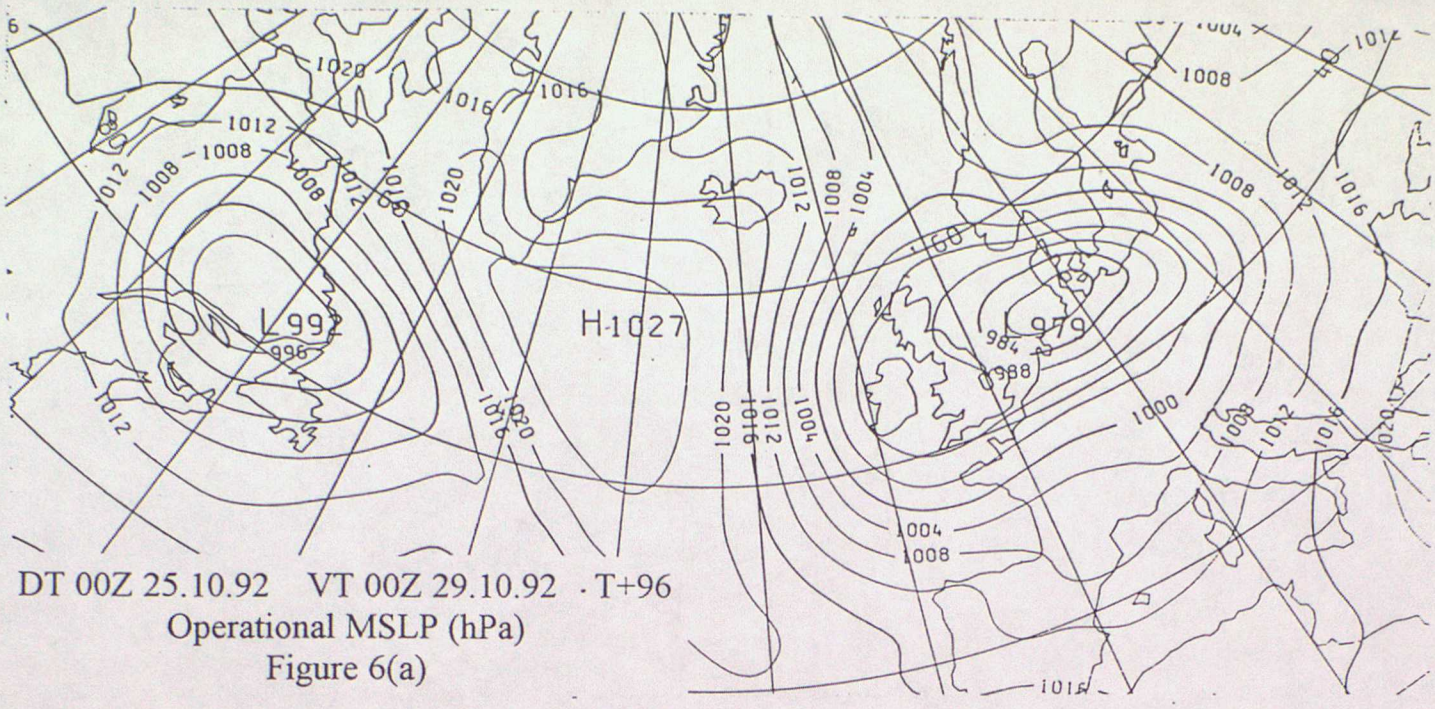
DT 00Z 22.10.92 VT 00Z 27.10.92 T+120
No Intervention 250hPa Isotachs (knots)
Figure 5(e)



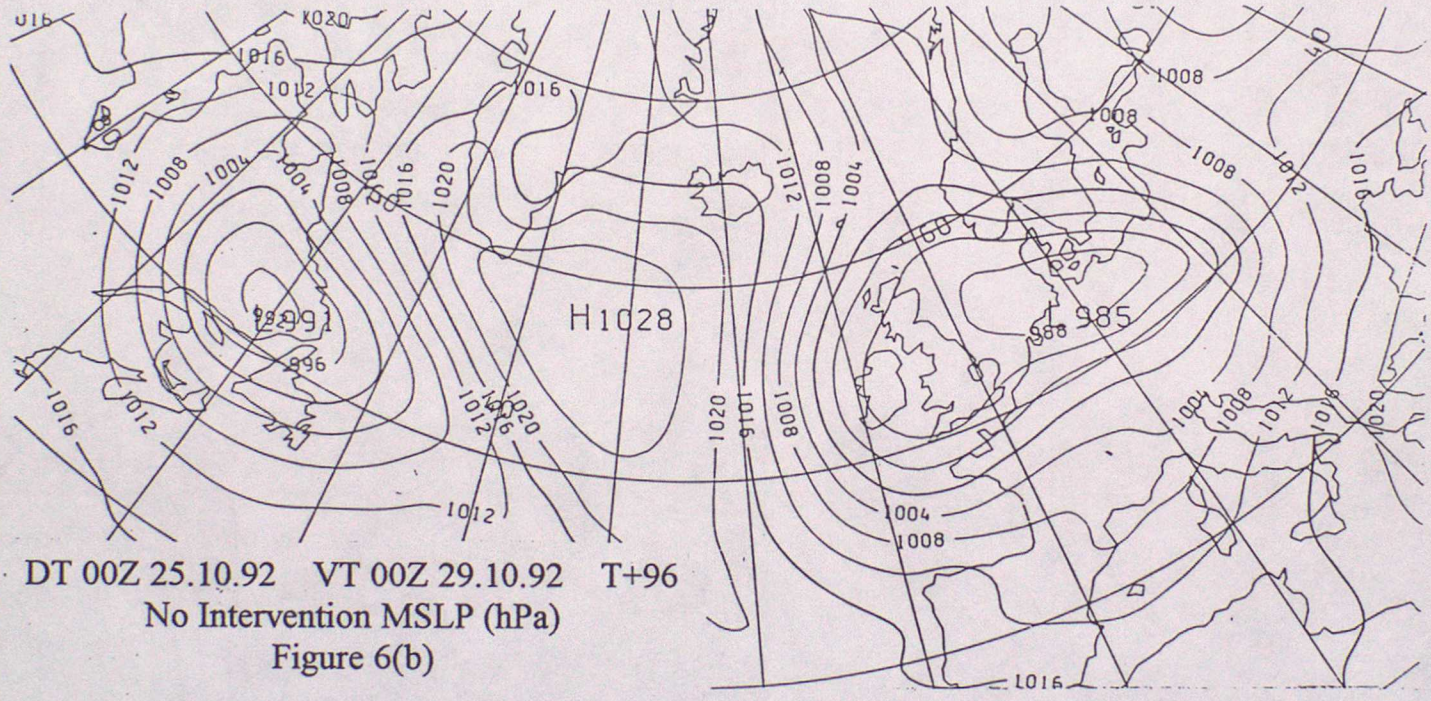
DT 00Z 22.10.92 VT 00Z 22.10.92 T+00
Operational 250hPa Isotachs (knots)
Figure 5(f)



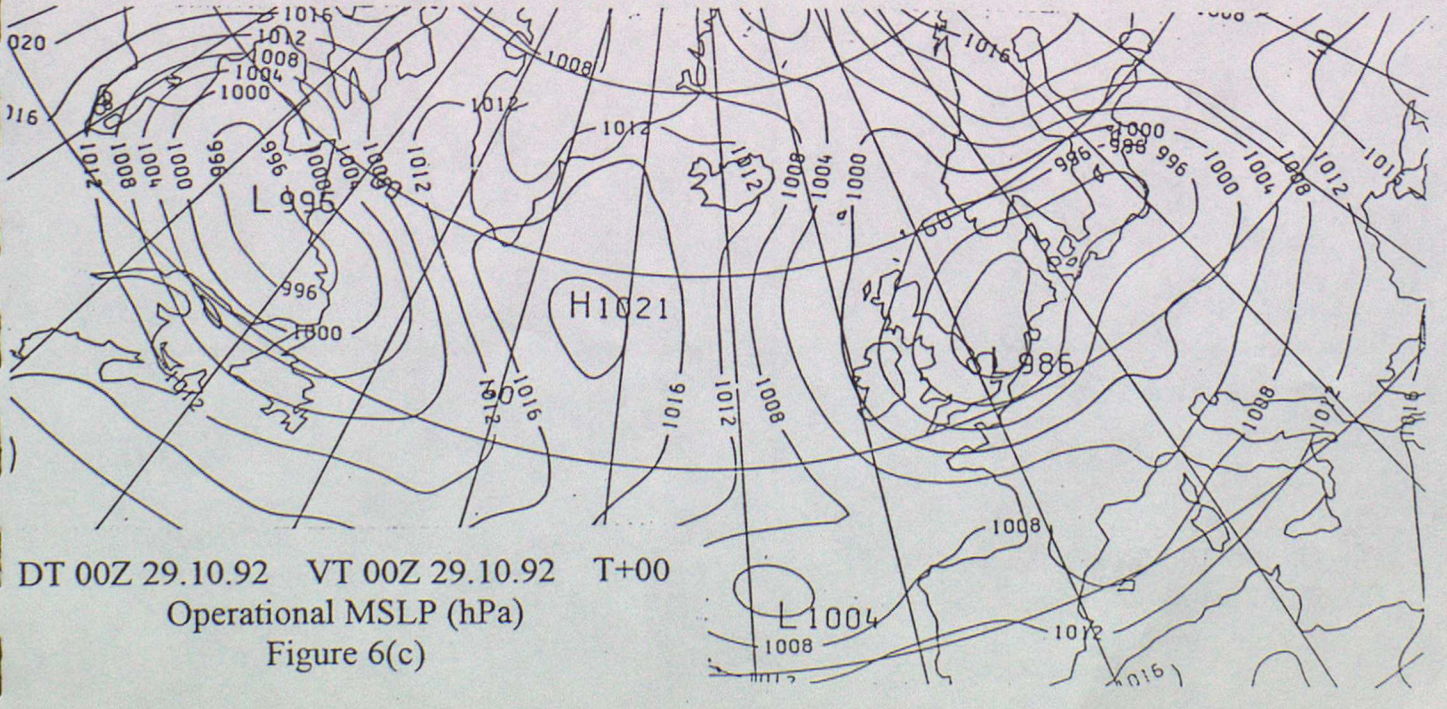
DT 00Z 22.10.92 VT 00Z 22.10.92 T+00
No Intervention 250hPa Isotachs (knots)
Figure 5(g)



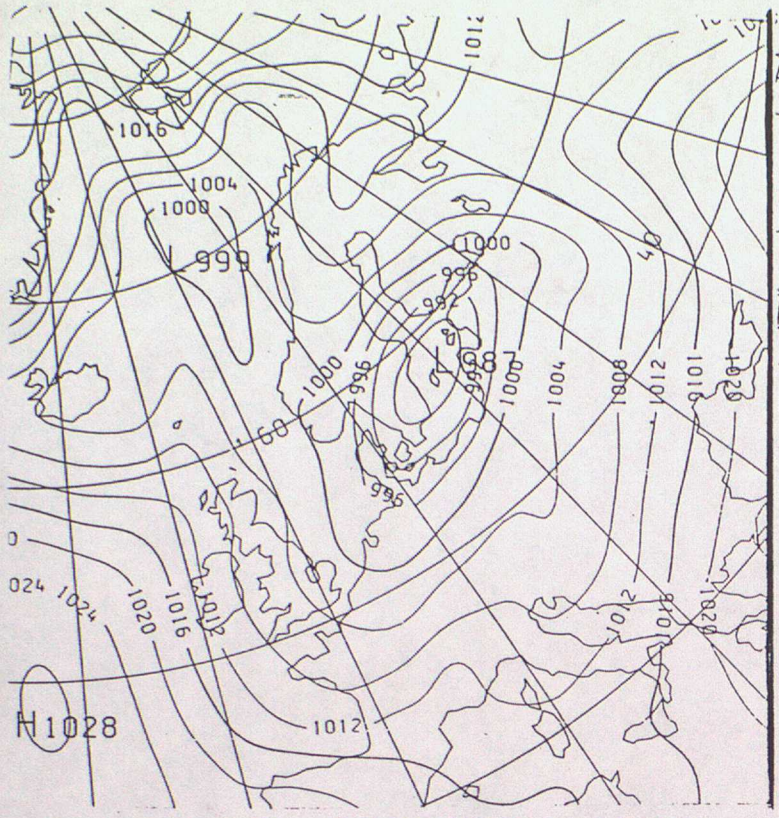
DT 00Z 25.10.92 VT 00Z 29.10.92 T+96
Operational MSLP (hPa)
Figure 6(a)



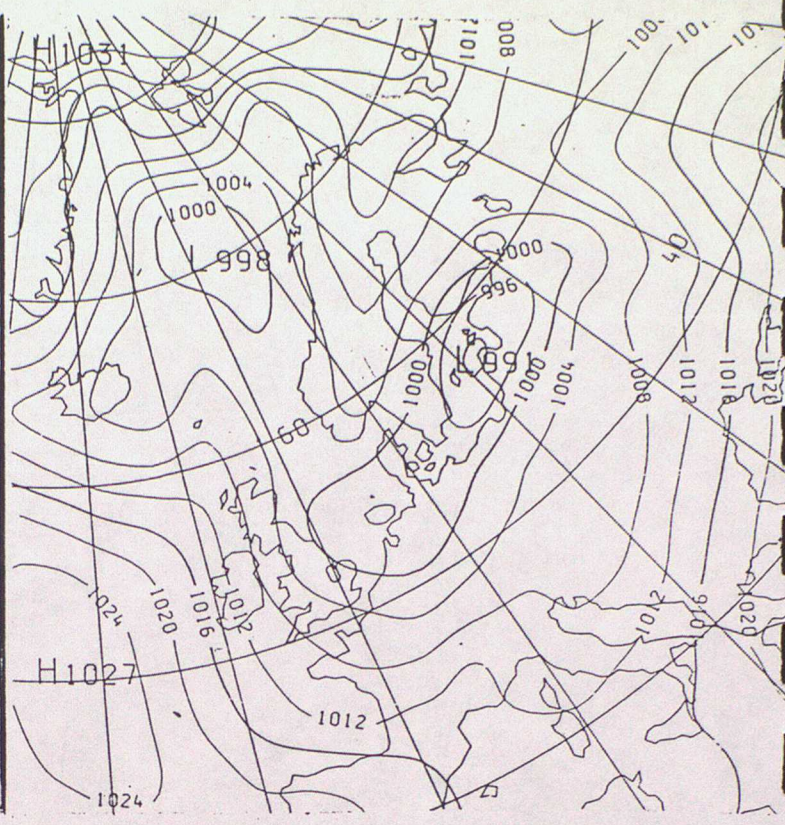
DT 00Z 25.10.92 VT 00Z 29.10.92 T+96
No Intervention MSLP (hPa)
Figure 6(b)



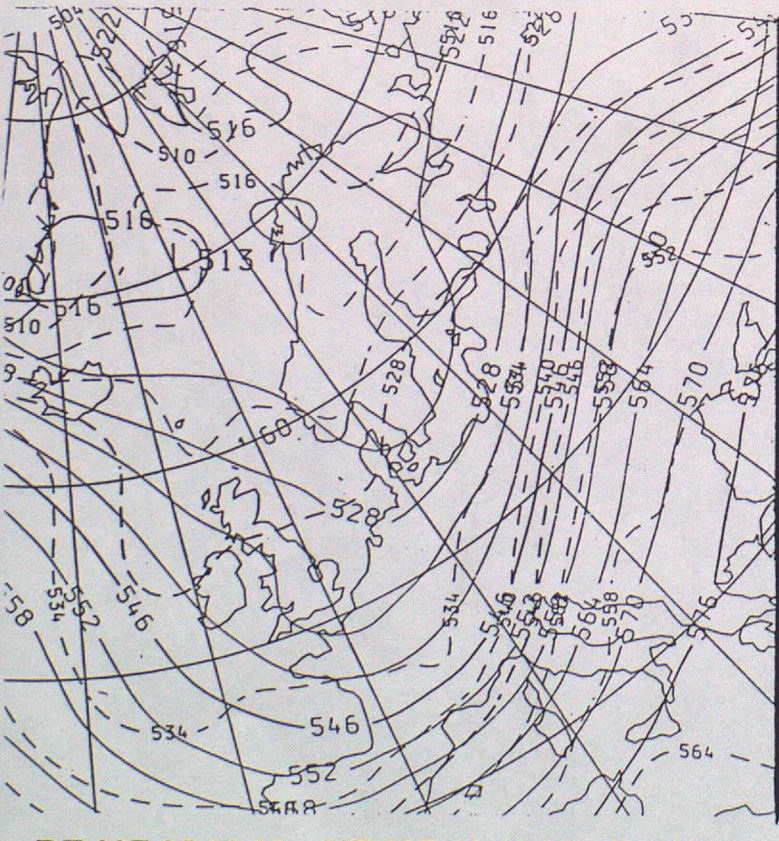
DT 00Z 29.10.92 VT 00Z 29.10.92 T+00
Operational MSLP (hPa)
Figure 6(c)



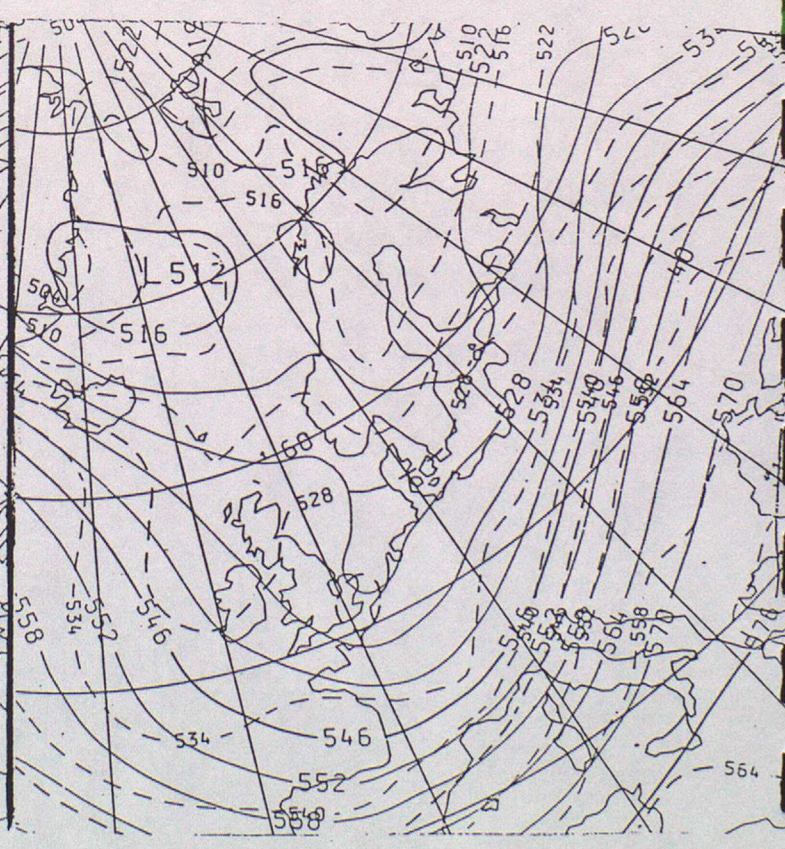
DT 00Z 25.10.92 VT 00Z 30.10.92 T+120
Operational MSLP (hPa)
Figure 6(d)



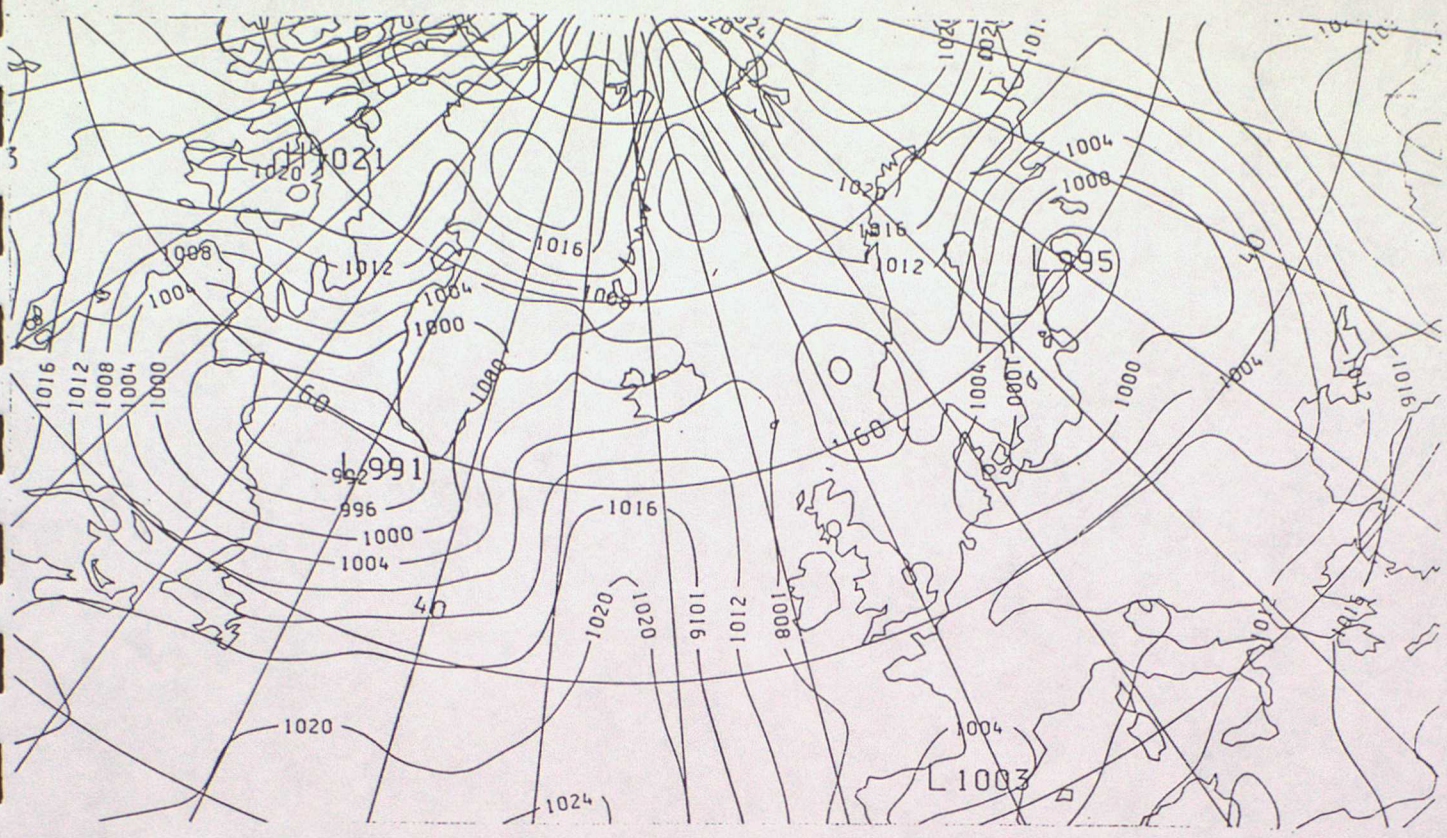
DT 00Z 25.10.92 VT 00Z 30.10.92 T+120
No Intervention MSLP (hPa)
Figure 6(e)



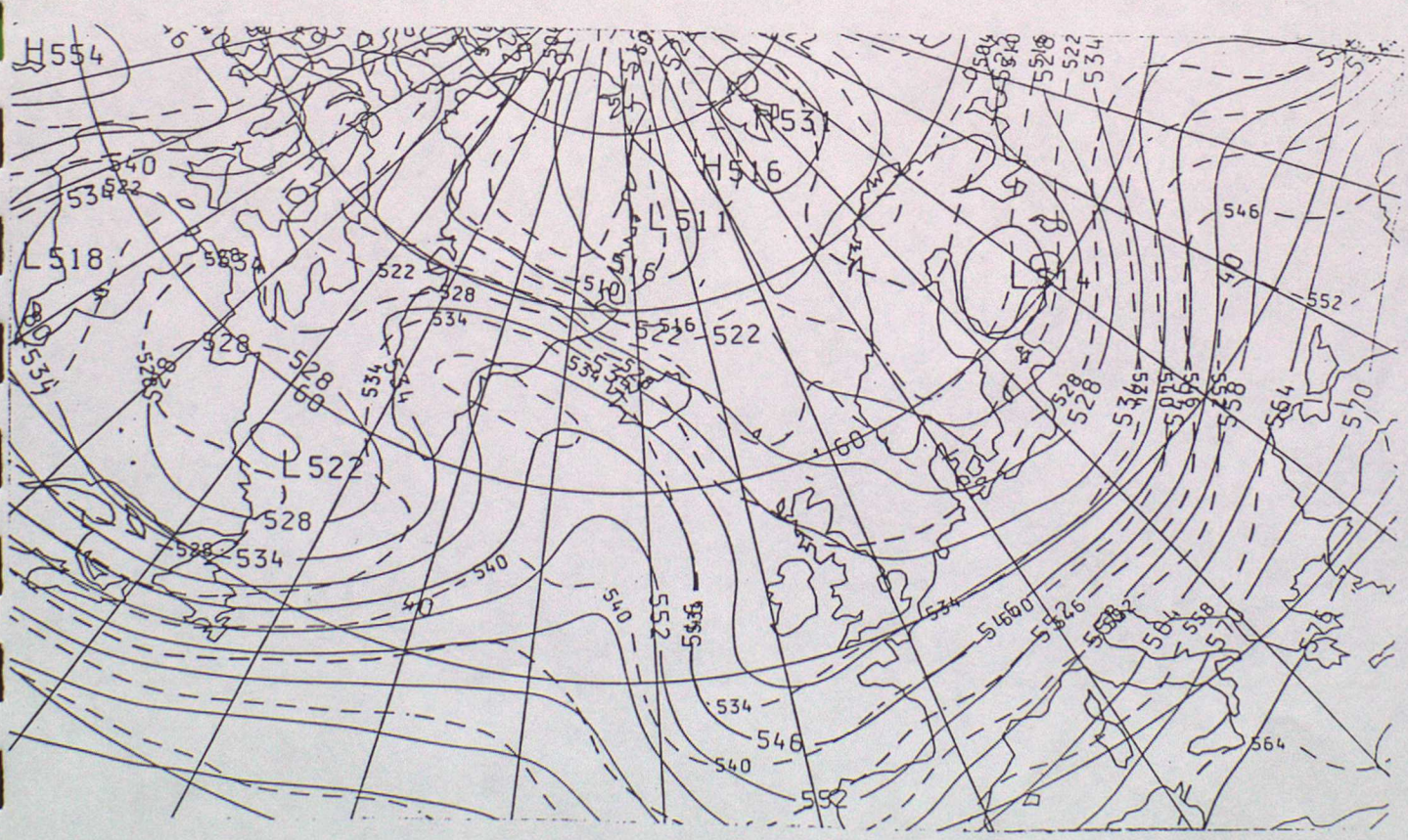
DT 00Z 25.10.92 VT 00Z 30.10.92 T+120
Operational 500-1000hPa Thickness &
500hPa Height (dam)
Figure 6(f)



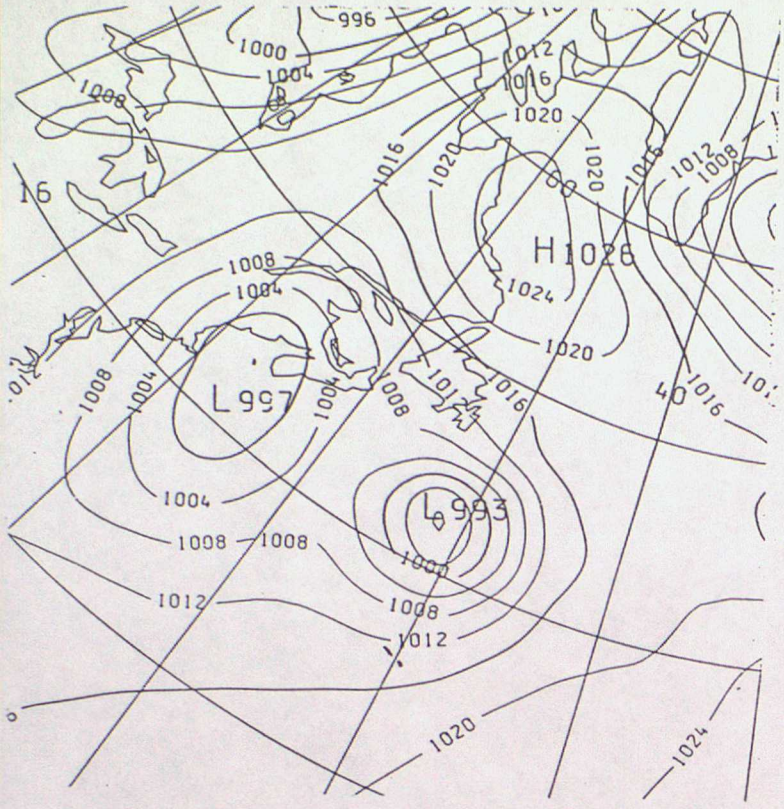
DT 00Z 25.10.92 VT 00Z 30.10.92 T+120
No Intervention 500-1000hPa Thickness &
500hPa Height (dam)
Figure 6(g)



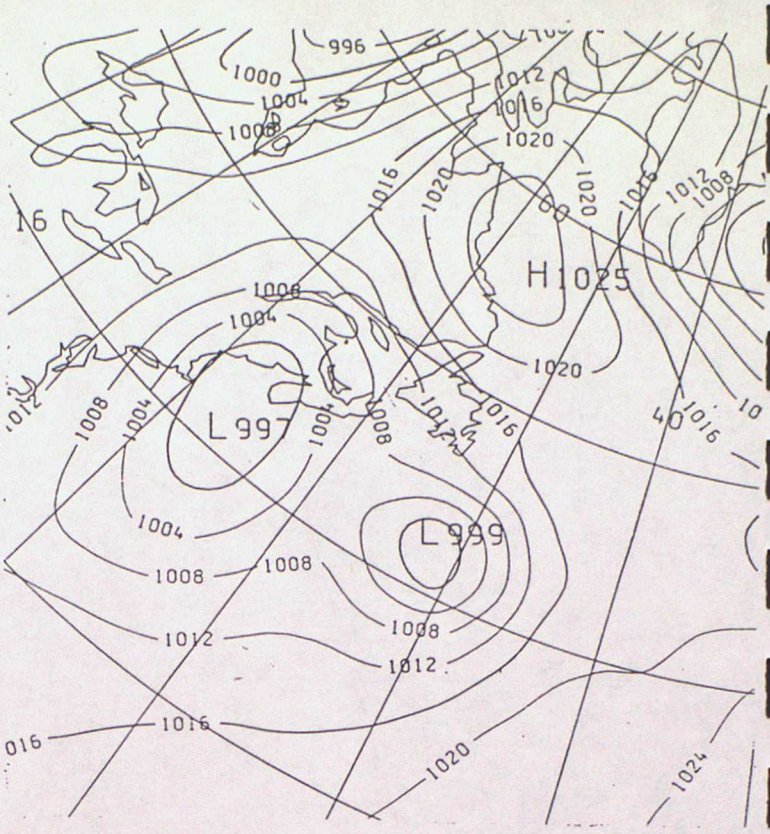
DT 00Z 30.10.92 VT 00Z 30.10.92 T+00
Operational MSLP (hPa)
Figure 6(h)



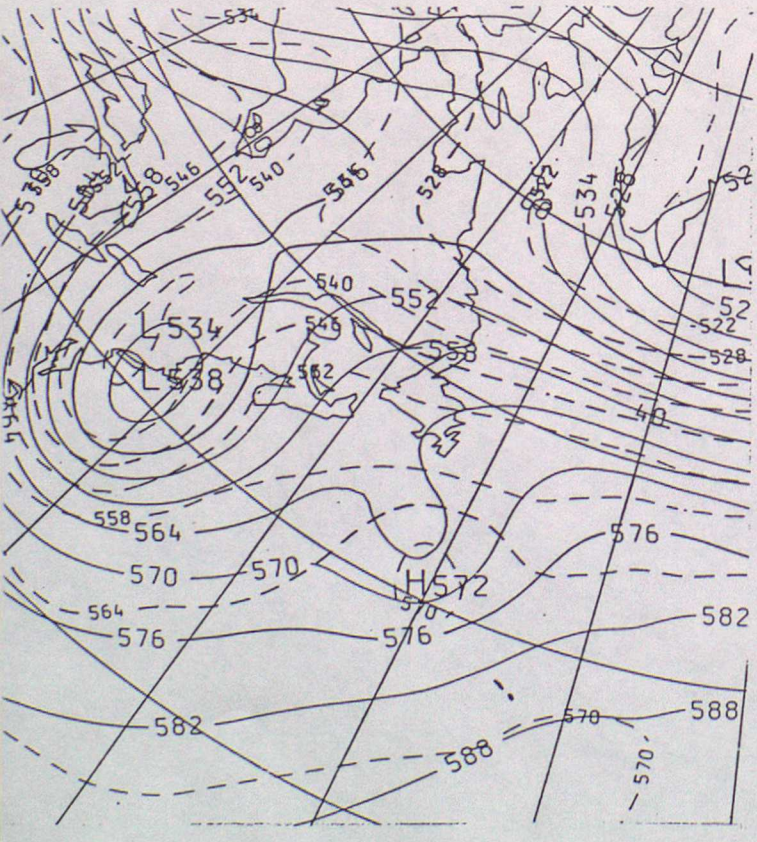
DT 00Z 30.10.92 VT 00Z 30.10.92 T+00
Operational 500-1000hPa Thickness &
500hPa Height (dam)
Figure 6(i)



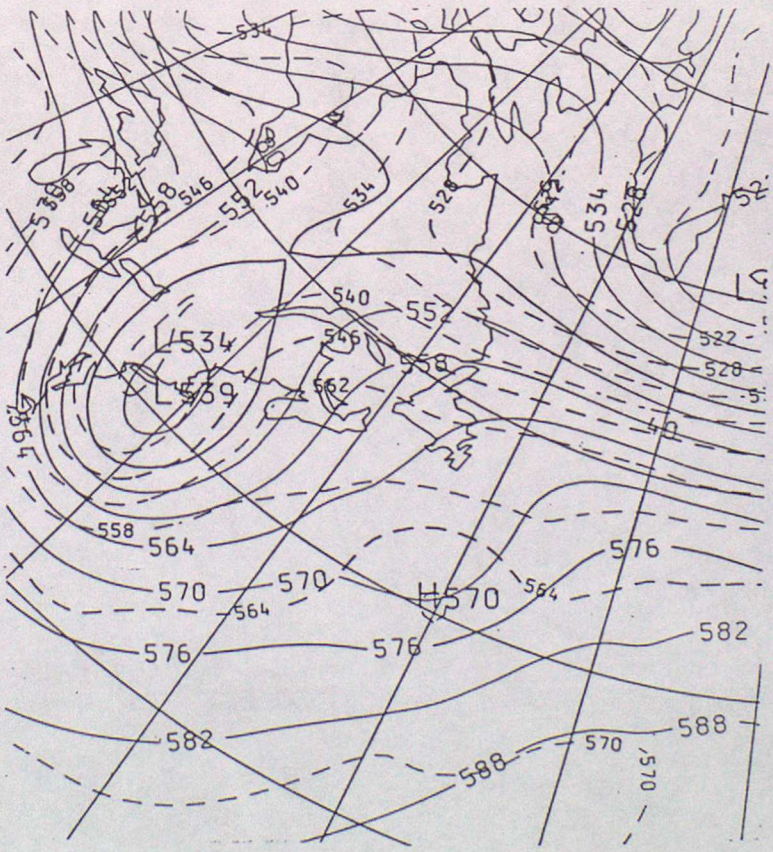
DT 00Z 26.10.92 VT 00Z 26.10.92 T+00
Operational MSLP (hPa)
Figure 7(a)



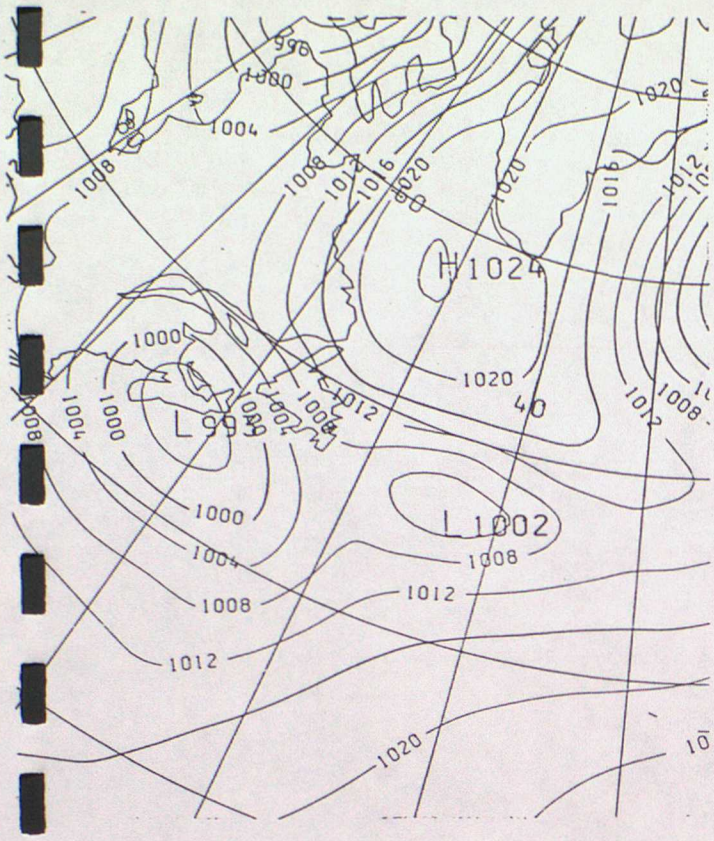
DT 00Z 26.10.92 VT 00Z 26.10.92 T+00
No Intervention MSLP (hPa)
Figure 7(b)



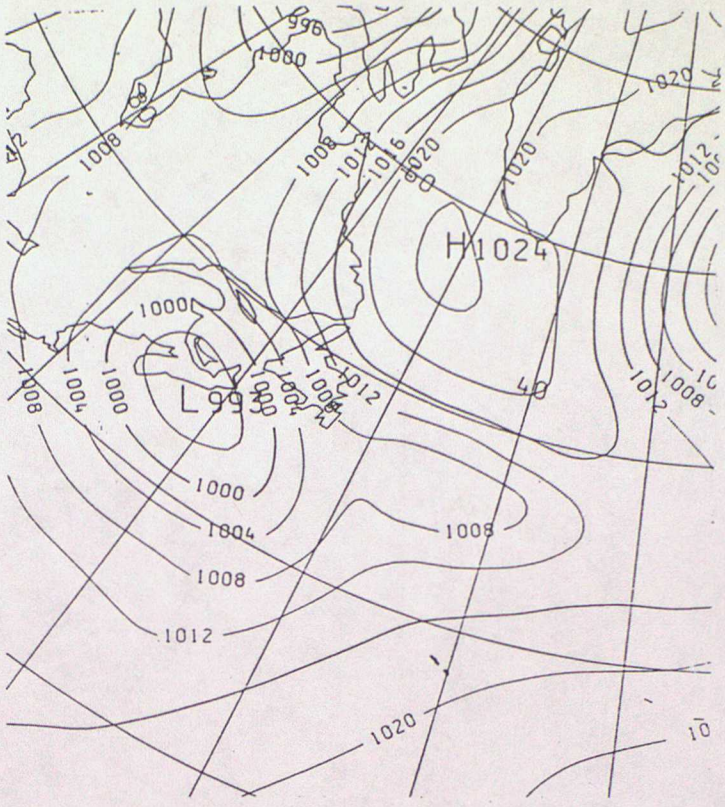
DT 00Z 26.10.92 VT 00Z 26.10.92 T+00
Operational 500-1000hPa Thickness &
500hPa Height (dam)
Figure 7(c)



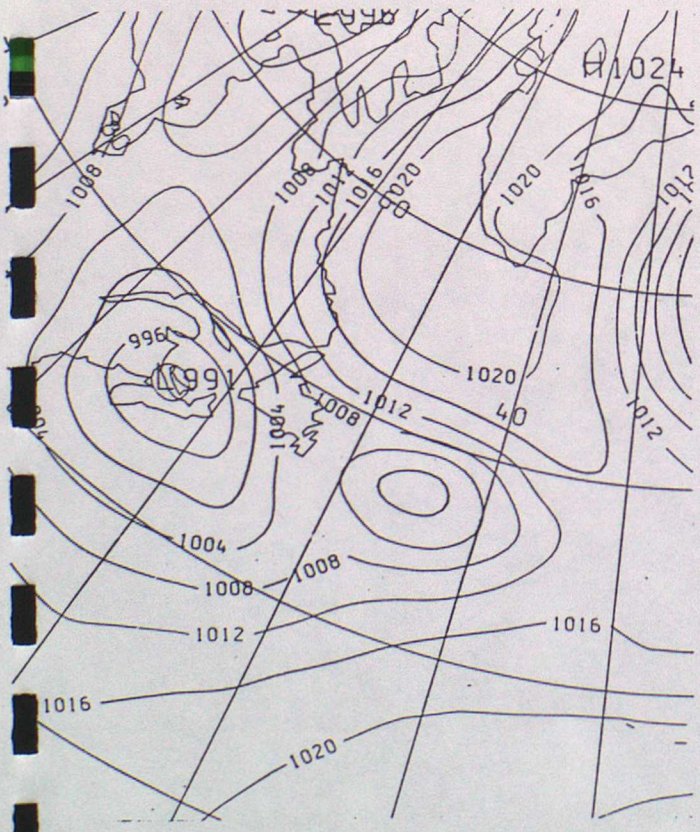
DT 00Z 26.10.92 VT 00Z 26.10.92 T+00
No Intervention 500-1000hPa Thickness &
500hPa Height (dam)
Figure 7(d)



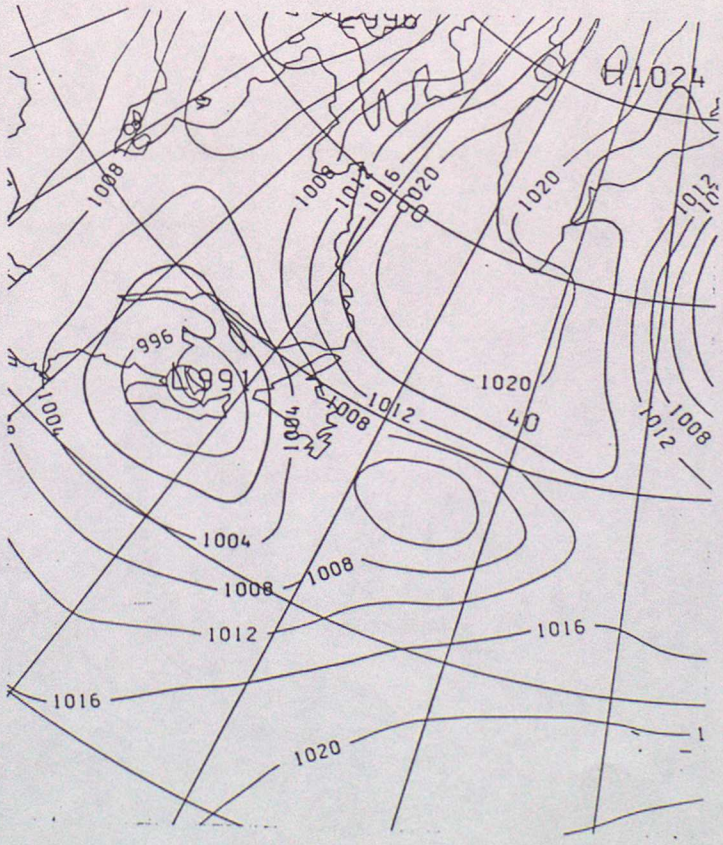
DT 00Z 26.10.92 VT 00Z 27.10.92 T+24
Operational MSLP (hPa)
Figure 7(e)



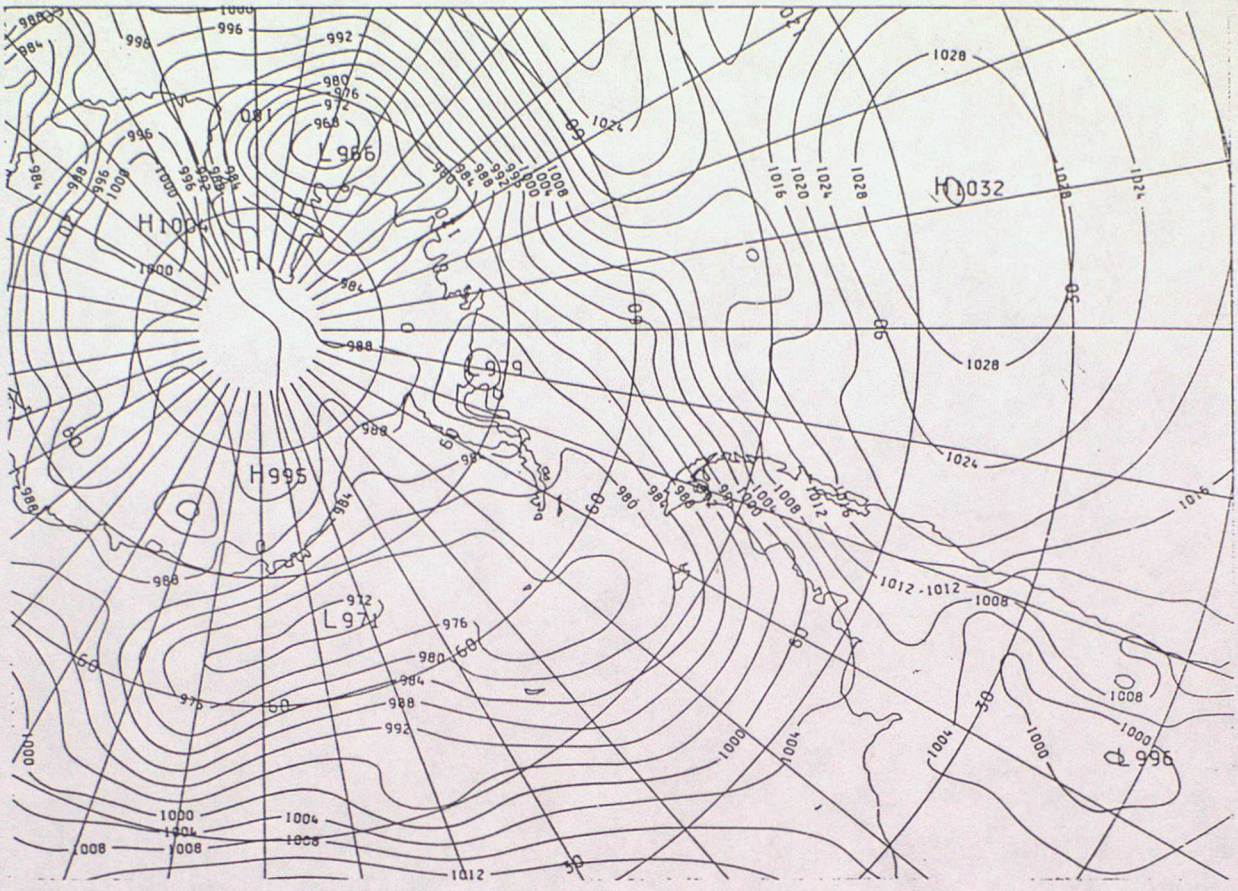
DT 00Z 26.10.92 VT 00Z 27.10.92 T+24
No Intervention MSLP (hPa)
Figure 7(f)



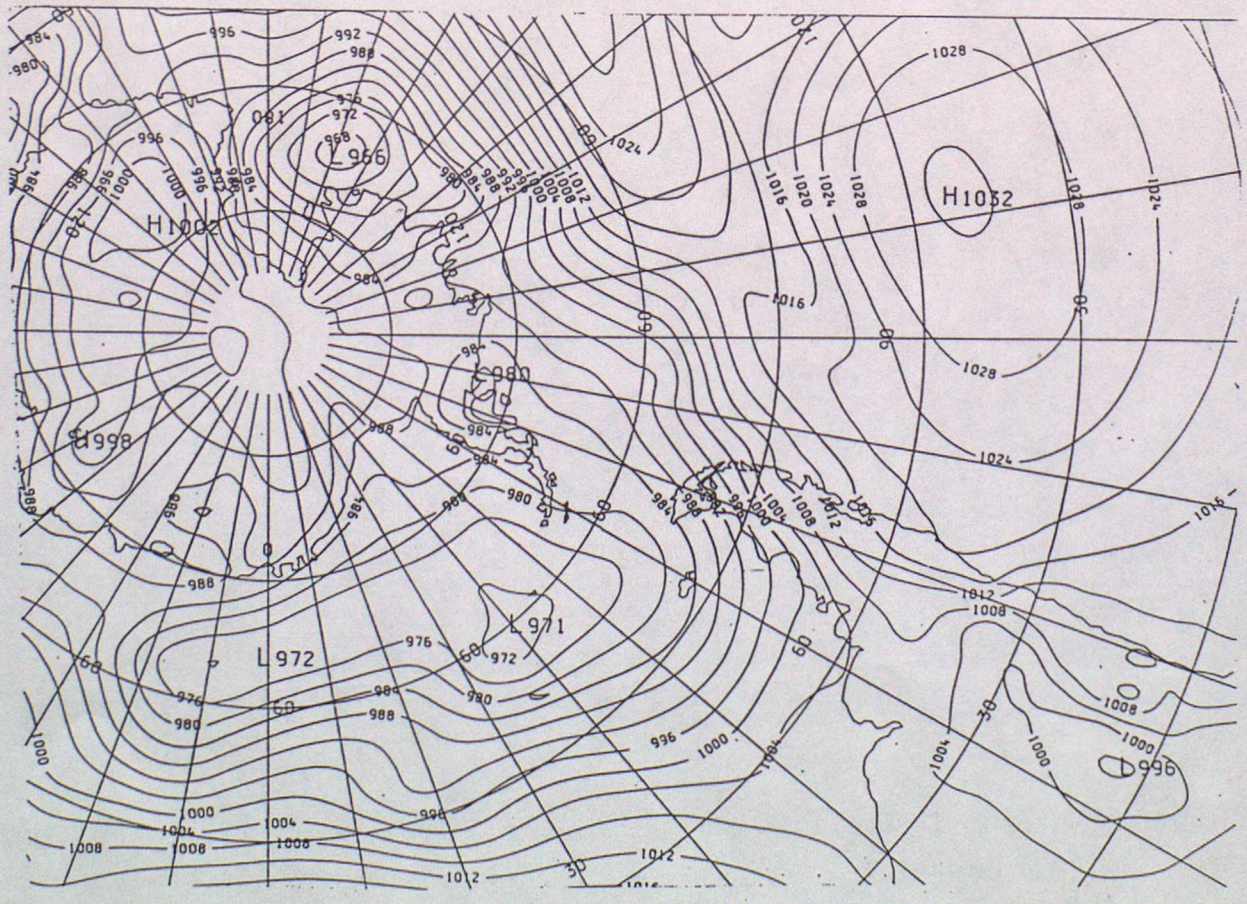
DT 00Z 27.10.92 VT 00Z 27.10.92 T+00
Operational MSLP (hPa)
Figure 7(g)



DT 00Z 27.10.92 VT 00Z 27.10.92 T+00
No Intervention MSLP (hPa)
Figure 7(h)

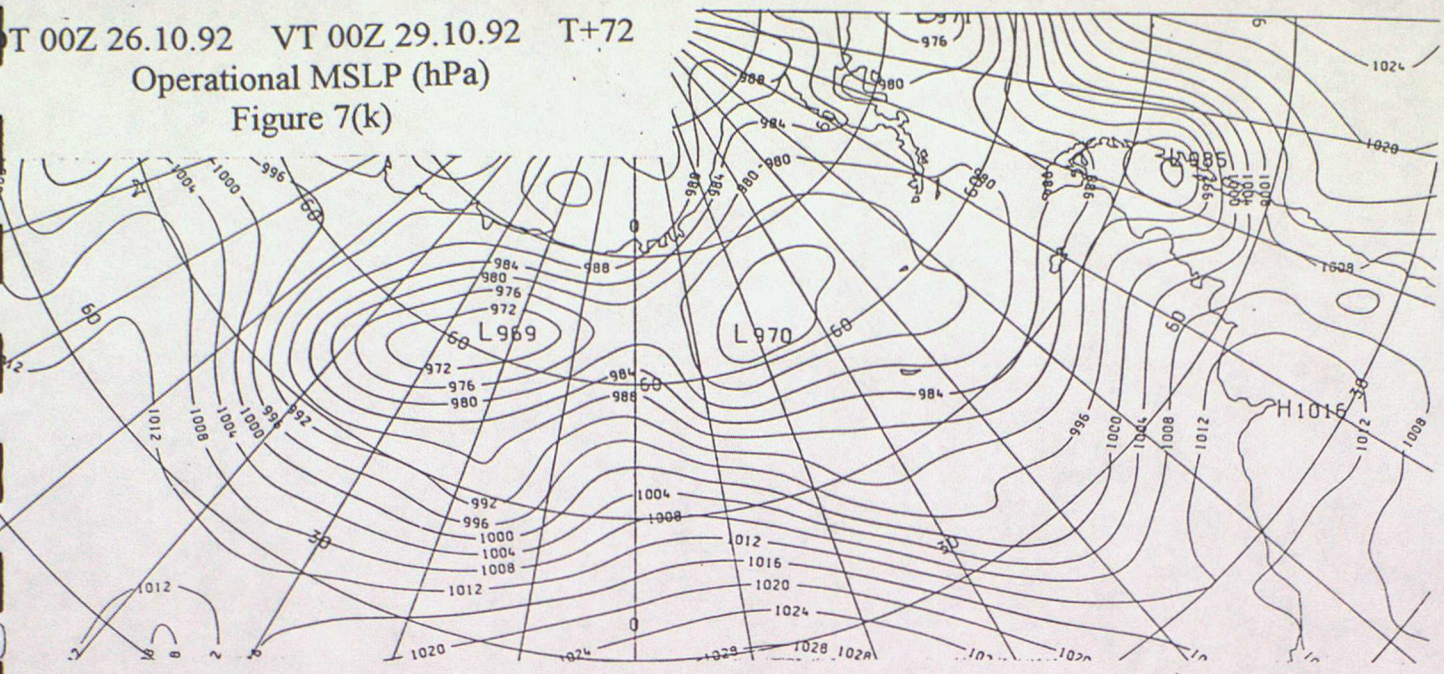


DT 00Z 26.10.92 VT 00Z 28.10.92 T+48
Operational MSLP (hPa)
Figure 7(i)

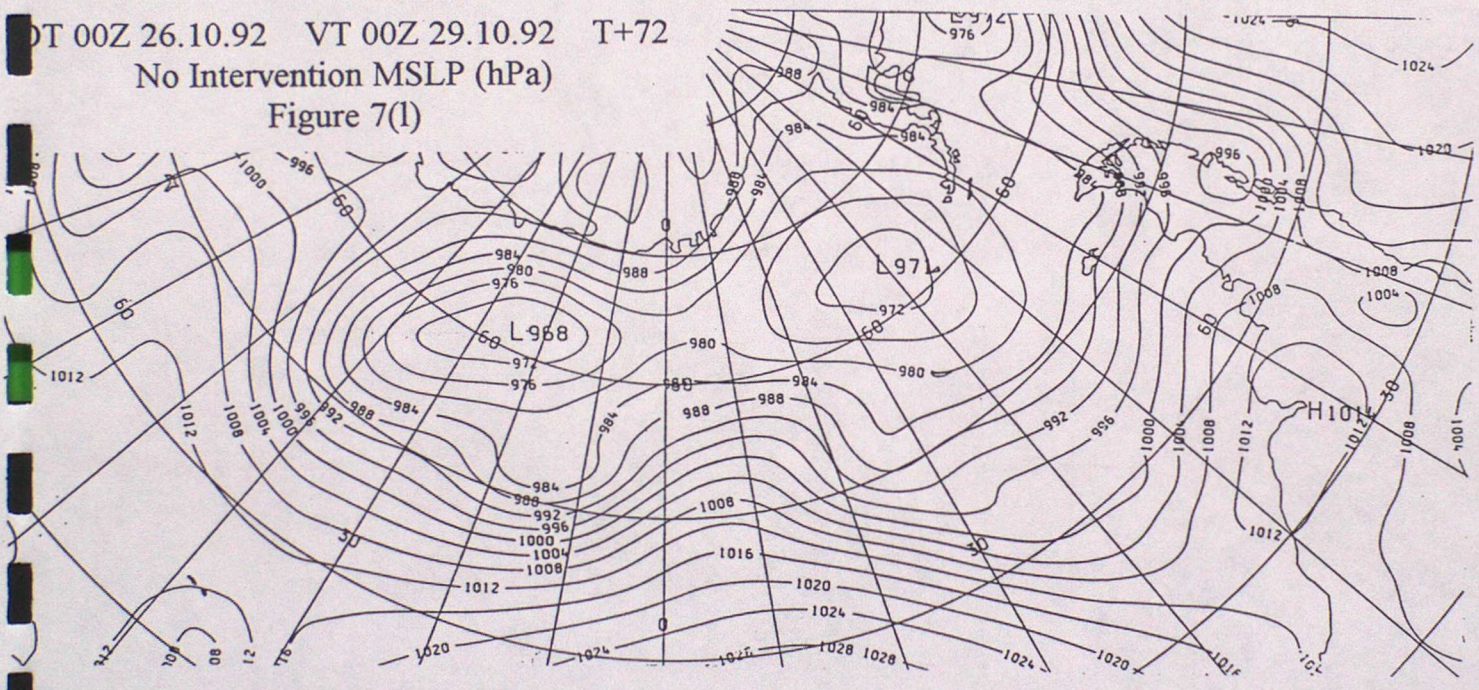


DT 00Z 26.10.92 VT 00Z 28.10.92 T+48
No Intervention MSLP (hPa)
Figure 7(j)

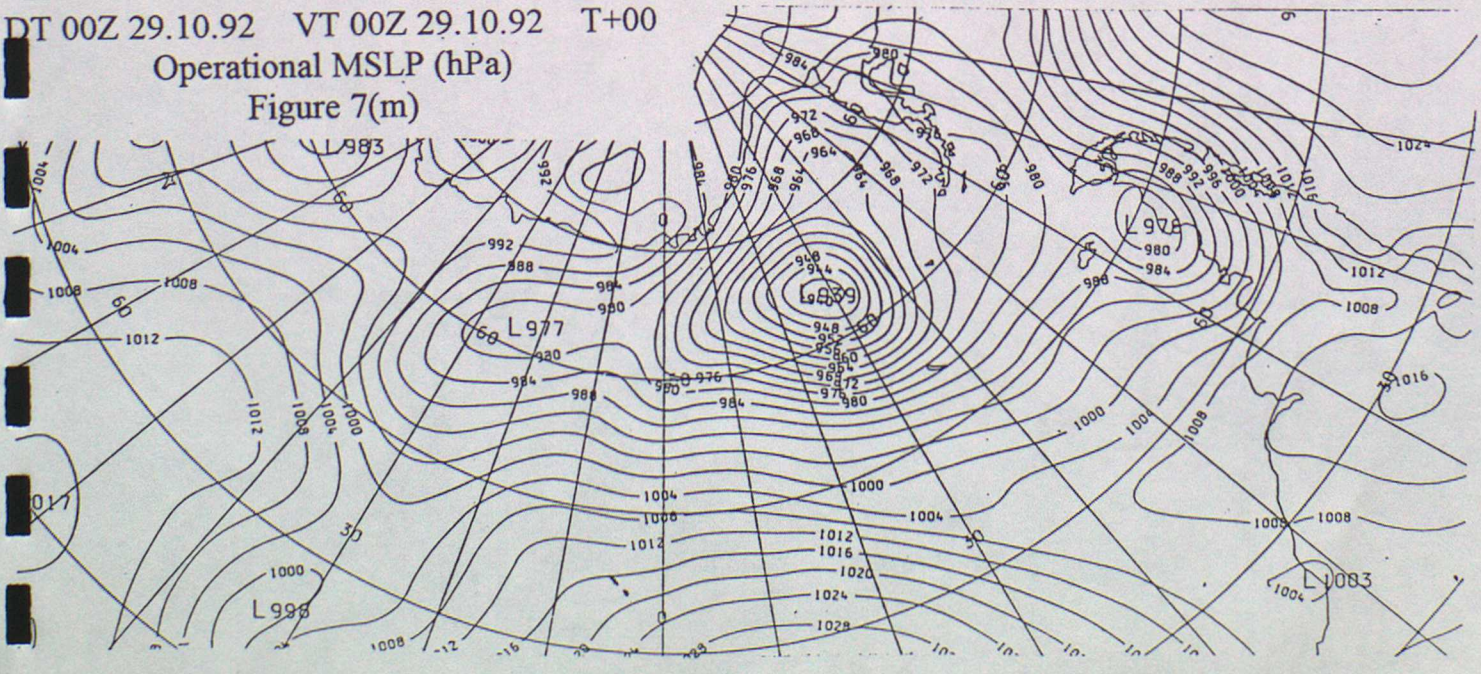
DT 00Z 26.10.92 VT 00Z 29.10.92 T+72
Operational MSLP (hPa)
Figure 7(k)

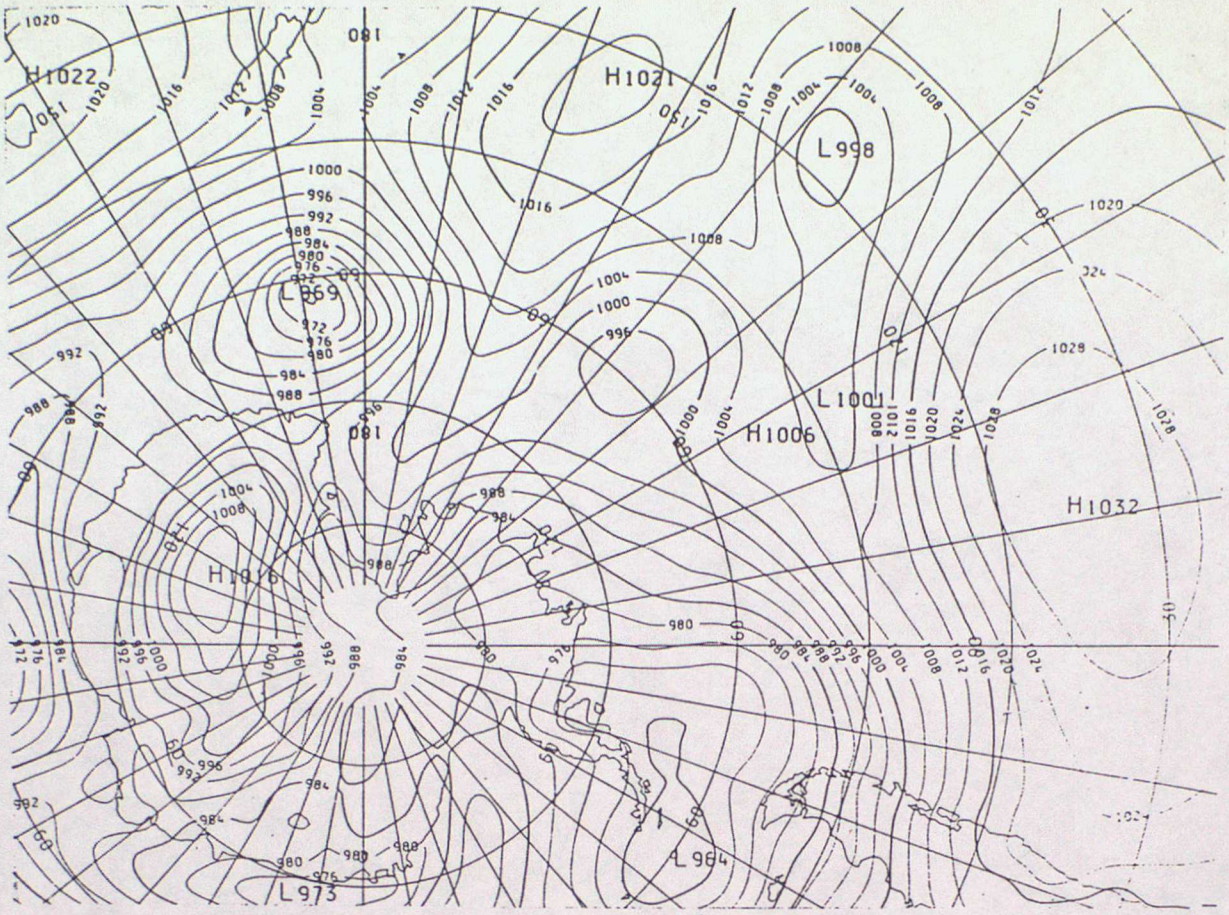


DT 00Z 26.10.92 VT 00Z 29.10.92 T+72
No Intervention MSLP (hPa)
Figure 7(l)

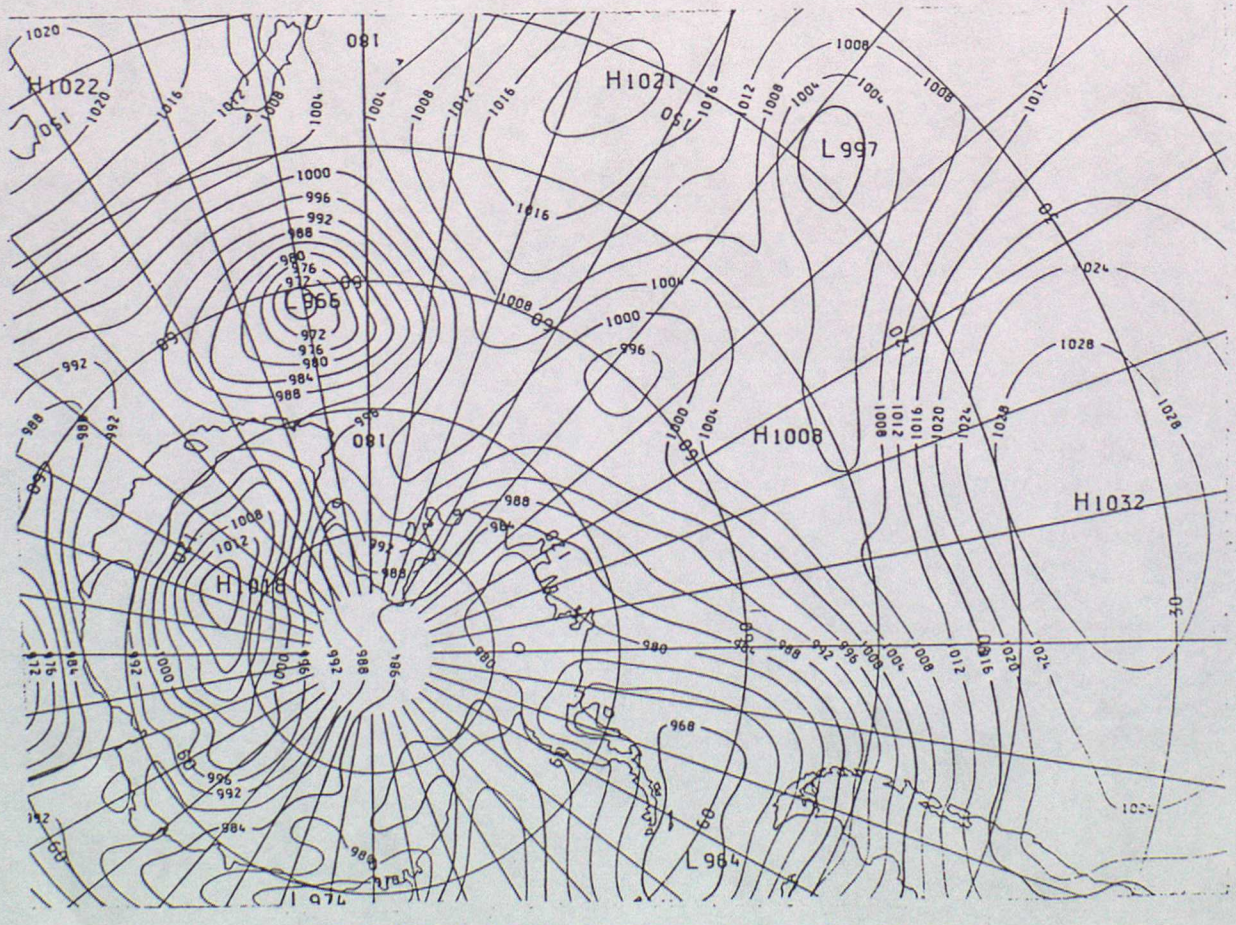


DT 00Z 29.10.92 VT 00Z 29.10.92 T+00
Operational MSLP (hPa)
Figure 7(m)



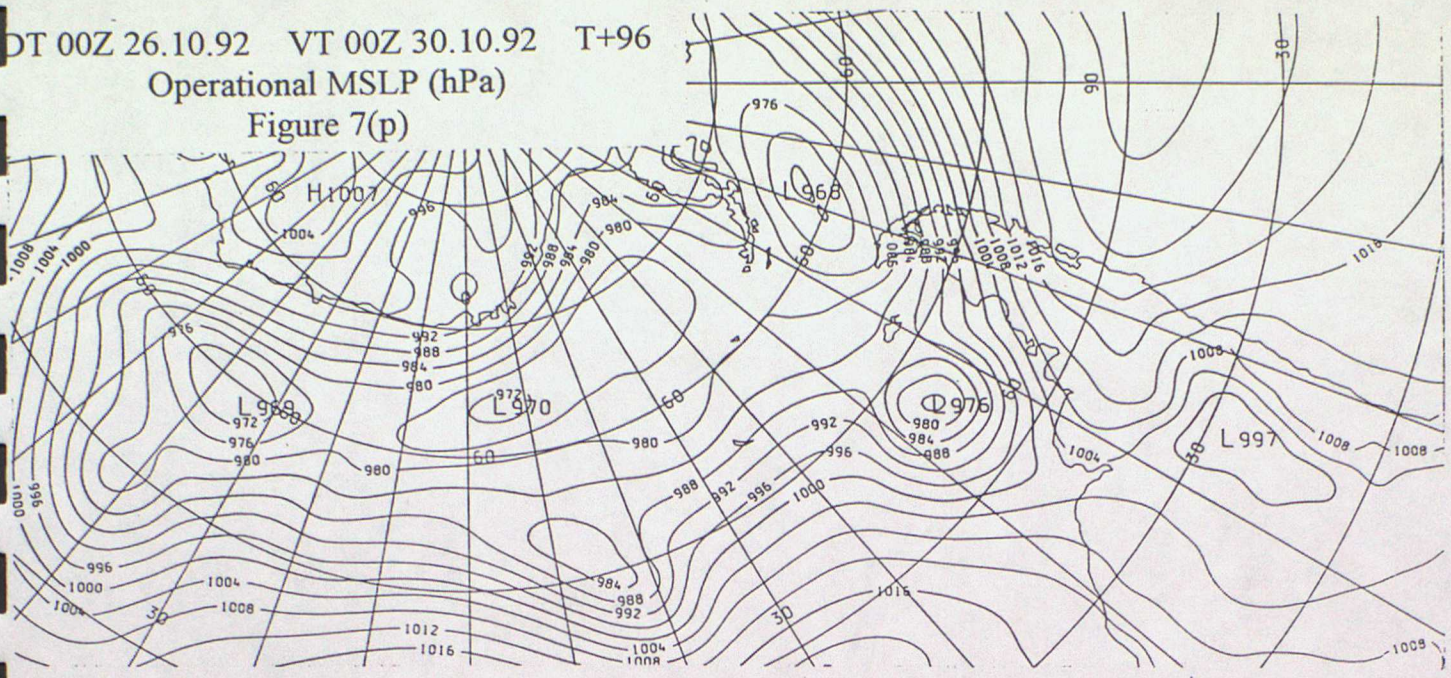


DT 00Z 26.10.92 VT 00Z 26.10.92 T+00
Operational MSLP (hPa)
Figure 7(n)

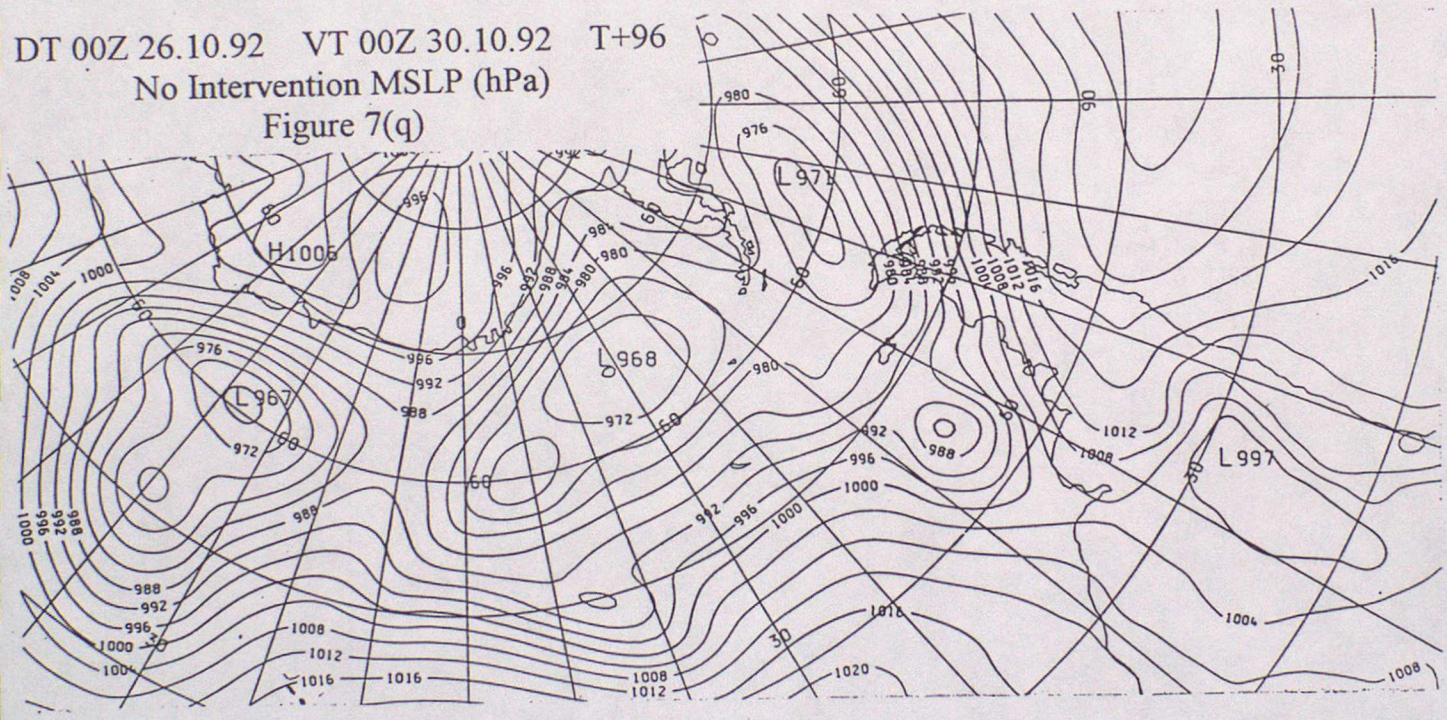


DT 00Z 26.10.92 VT 00Z 26.10.92 T+00
No Intervention MSLP (hPa)
Figure 7(o)

DT 00Z 26.10.92 VT 00Z 30.10.92 T+96
Operational MSLP (hPa)
Figure 7(p)



DT 00Z 26.10.92 VT 00Z 30.10.92 T+96
No Intervention MSLP (hPa)
Figure 7(q)



DT 00Z 30.10.92 VT 00Z 30.10.92 T+00
Operational MSLP (hPa)
Figure 7(r)

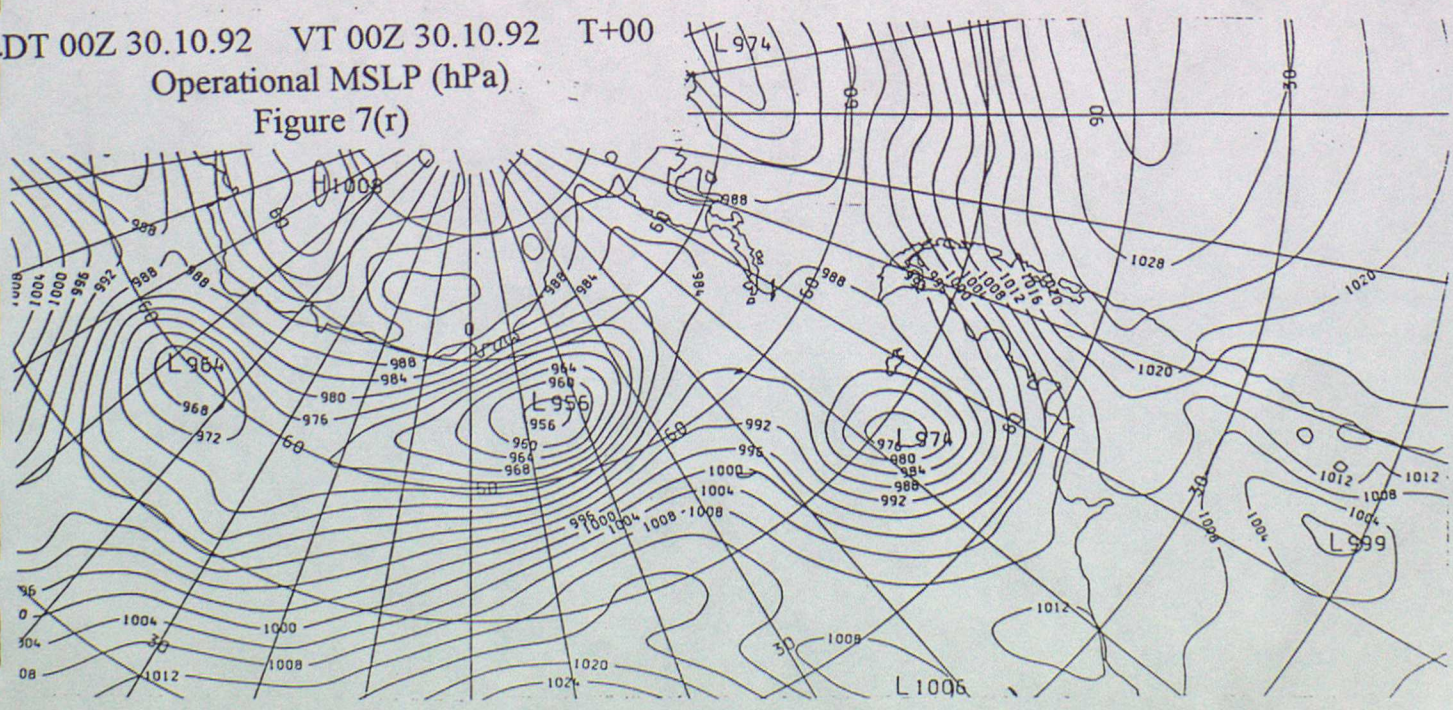


Figure 8.
Verification Against Observations.
MSLP RMS Errors

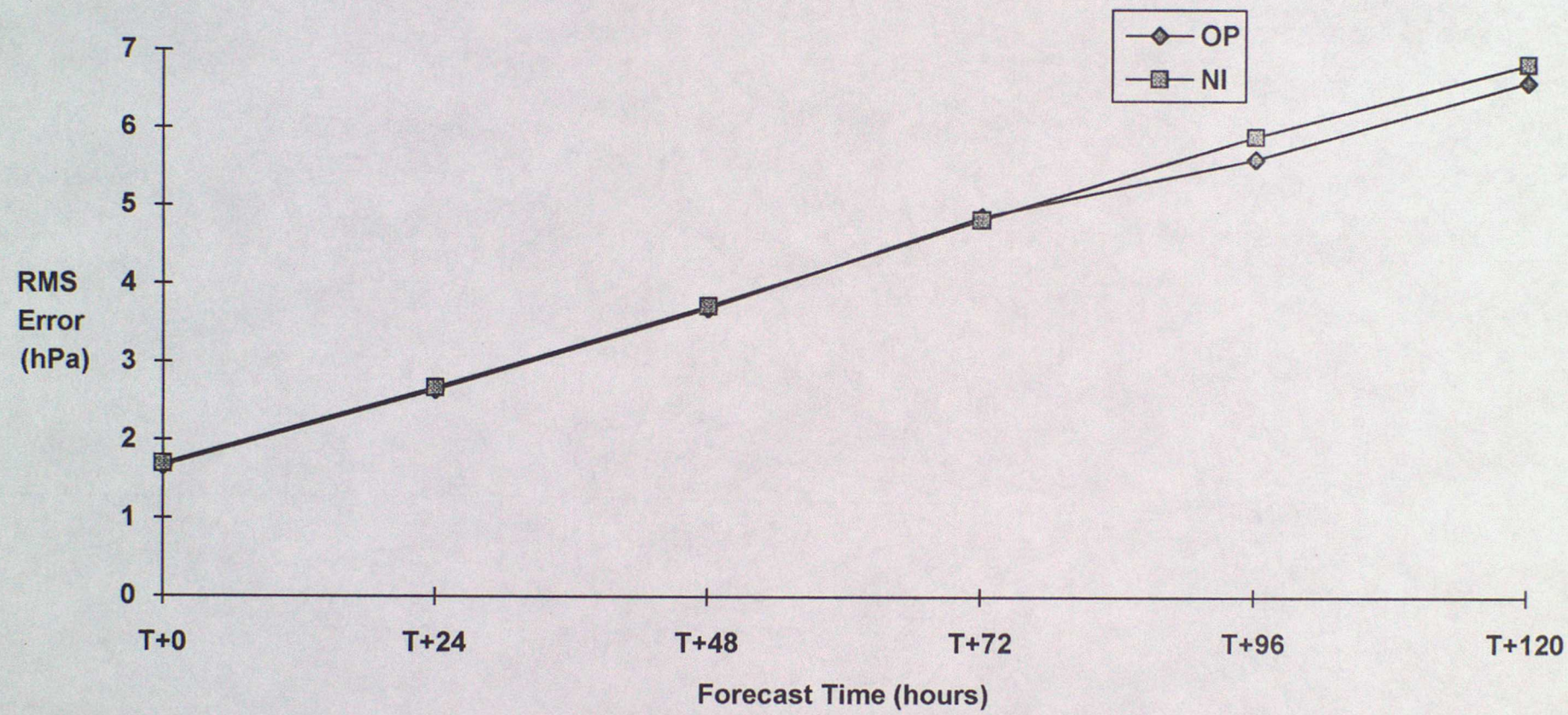
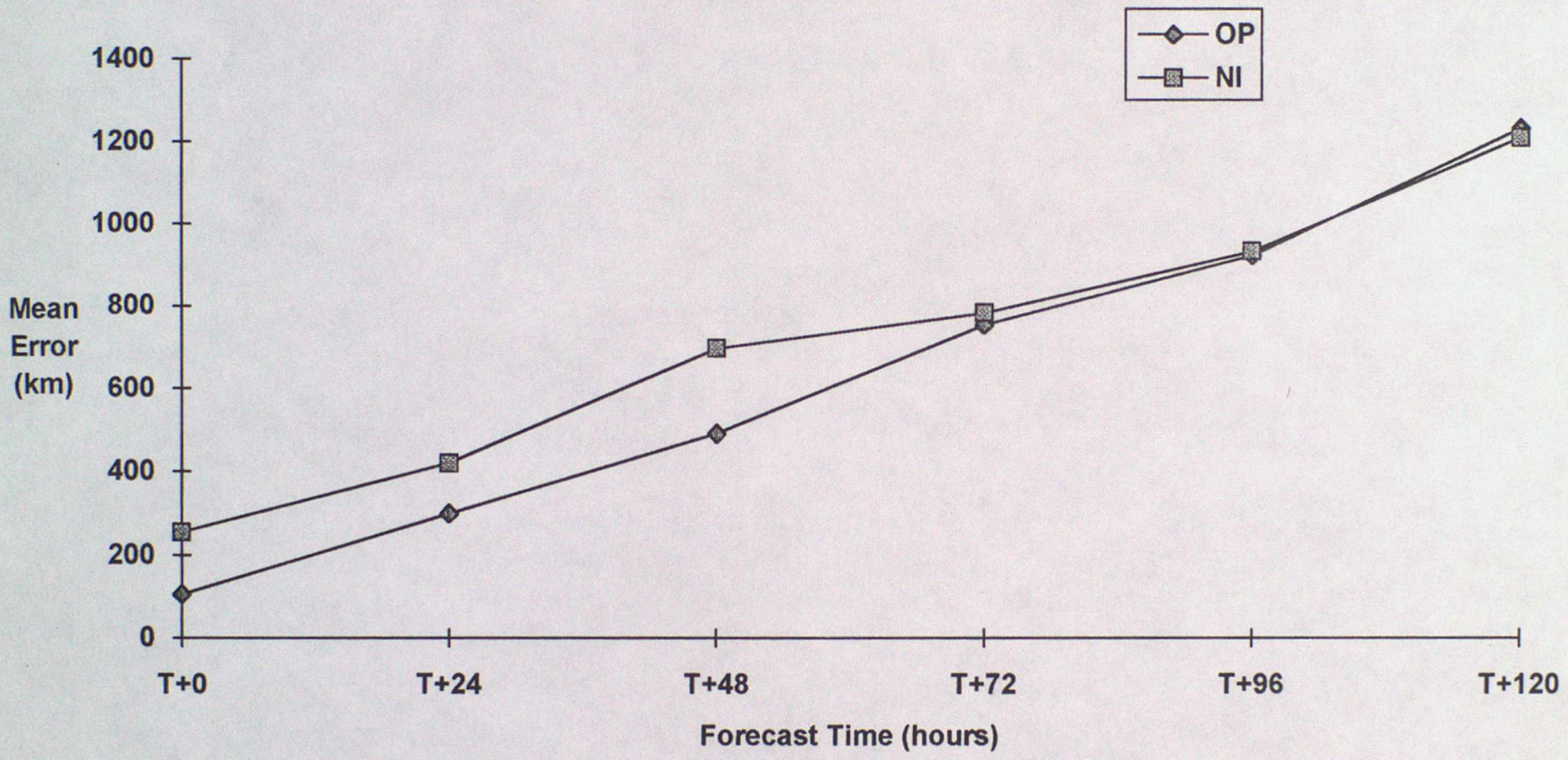



Figure 9.
Verification of Tropical Cyclones.
Mean Positional Errors.